BOILER EXPLOSIONS, COLLAPSES AND MISHAPS

BOILER EXPLOSIONS, COLLAPSES AND MISHAPS

Being a Summary of the Causes of Boiler Explosions and the Recommendations for their Prevention contained in the Reports of the Board of Trade from 1882 *to* 1911

TOGETHER WITH

A Statement of the Statutory Duties of Steam Users and their Liabilities as Defined by the Commissioners holding Investigations under the Boiler Explosions Acts

BY

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WITH AN INTRODUCTION BY

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INTRODUCTION

It is not every one who has the capacity or leisure for the scientific study of boilers and their care. But there are few persons who would not find some knowledge of the duties and obligations connected with their use or misuse an advantage or a security. To supply this knowledge in a form easily assimilated and legally and scientifically accurate is the object of this work.

The author, Mr. Rimmer, with this object in view, has brought an engineering as well as a legal training to bear on the subject, and he has produced a book full of valuable information which ought to be in the hands of all steam users. Should an explosion unfortunately occur, whether accompanied by injury to persons or by loss of life or not, this work cannot fail to be of great assistance to those engaged in the statutory and other proceedings which may follow.

A. A. HUDSON,

ONE OF THE COMMISSIONERS UNDER THE BOILER EXPLOSIONS ACTS.

May, 1912.

PREFACE

In this small volume the author has endeavoured to bring together the results of all the inquiries and investigations made under the Boiler Explosions Acts, 1882 and 1890.

There have been over two thousand of these inquiries, and though each in turn has been the subject of comment at the time by the Engineer-Surveyor-in-Chief to the Board of Trade or by the Commissioners holding the investigation, the lessons which they teach have perhaps been forgotten or have never been brought to the notice of the general body of steam users. It is true that the boiler insurance companies, through their engineers, have warned those who insure with them against the more common causes of explosion, but the record of Board of Trade experience contained herein will, it is believed, bring more forcibly to the minds of owners and users of boilers the dangers of disaster and their responsibilities in respect to their plant.

It is also of great importance to a steam user to ascertain correctly the cause of an explosion. Blame or liability may be attached either to himself or some other person according to the decision of this question.

A coroner's jury has the power to incorporate in its finding a decision as to the cause of an explosion. At such an inquest the coroner is usually assisted by an engineer, who, selected by the coroner, may not always have the experience necessary to found a proper decision. Such engineer does not go into the witness box, but makes a

report to the coroner and sits with him to advise him. A factory inspector may also attend the coroner's inquiry and ask questions, nominally for the purpose of testing whether the Factory Acts have been complied with, but sometimes to support some theory which he has formed as to the cause. Factory inspectors are seldom boiler experts.

The Board of Trade surveyors, holding their preliminary inquiry, generally make a thorough investigation. They are usually competent boiler engineers, but are not infallible, and the engineers of boiler insurance companies have often questioned the opinions expressed by them in their reports. It is upon their report that the Board of Trade decides whether a formal investigation should be held.

The formal investigation and the judgment of the Commissioners, carrying with it perhaps censure and order for costs, does not affect the civil liabilities of the parties, but it cannot be ignored as a powerful weapon of cross-examination in a court of law.

From the foregoing it is clearly important to the parties interested in an explosion that no incorrect theory, carrying with it blame or liability to themselves, should be upheld at any of the above inquiries.

In order to warn steam users of danger, and to assist them to come to correct conclusions as to the cause of an explosion, the author has endeavoured to place before his readers in concise statements all the material points in the thirty years' experience of the Board of Trade with reference to reports of greater length, and whenever opinion is expressed it may be corroborated by the report or other authority quoted.

In reading through the Reports of the Board of Trade the author has been particularly impressed with the beneficent work done by the boiler insurance companies.

These companies are not merely insurers of boilers, but by the employment of an outside staff of inspectors and a technical indoor staff of engineers they give expert advice to their assured as to the safe working pressure and proper management of their boilers and steam plant. *They guarantee the safety of the boiler*, and only about 8 per cent. of the boilers involved in the reports were under the inspection of these boiler insurance companies, whilst in remarkably few cases has explosion or collapse of a boiler been attributed to the fault of inspection or error of judgment of the engineers of the company. Also by advice and recommendations given to their assured from time to time, these companies do much to mitigate the danger of explosion from ignorant or improper management. The first such company was an association founded in 1854 (now the Manchester Steam Users Association) and called "The Association for the Prevention of Steam Boiler Explosions, and for effecting economy in the raising and use of steam," and this association has been followed by the other five insurance companies formed for the same purpose, namely (in alphabetical order):—

The British Engine Boiler and Electrical Insurance Company.

The National Boiler Insurance Company.

The Ocean Accident and Guarantee Corporation.

The Scottish Boiler Insurance and Engine Inspection Company.

The Vulcan Boiler and General Insurance Company.

The industrial utility of these companies is largely due to their foundation and careful early working by such men as Sir William Fairbairn, Mr. R. B. Longridge, Mr. H. Hiller, and Mr. Lavington Fletcher.

The author wishes to acknowledge with thanks the readiness with which the present chief engineers of the

boiler insurance companies have given him permission to reproduce facts and figures contained in their memoranda and publications. In particular he would mention Mr. C. E. Stromeyer, the Chief Engineer of the Manchester Steam Users Association, for permission to quote freely from his memoranda, and especially from his valuable paper on Waterhammer; Mr. Michael Longridge, the Chief Engineer of the British Engine Boiler and Electrical Insurance Company, for permission to reproduce tables from his annual reports. It was from these valuable reports that the author framed the arrangement of Section 3; Mr. Edward G. Hiller, the Chief Engineer of the National Boiler Insurance Company, for permission to quote from his handbook for the use of boiler attendants and those in charge of and responsible for steam boilers—"Working of Steam Boilers"; and the Chief Engineers of the Ocean Accident and Guarantee Corporation, the Scottish Boiler Insurance Company, and the Vulcan Boiler and General Insurance Company, for permission to reproduce their instructions to firemen, etc.

E. J. R.

13, Harrington Street,
Liverpool,
May, 1912.

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BOILER EXPLOSIONS, COLLAPSES AND MISHAPS

Section 1

LEGISLATION IN REGARD TO BOILERS AND BOILER EXPLOSIONS

All legislation in regard to boilers and boiler explosions is contained in the following statutes:—

Boiler Explosions Acts, 1882 and 1890.
Factory and Workshop Act, 1901.
Railway Regulation Act, 1871.
Metalliferous Mines Regulation Act, 1872.
Coal Mines Act, 1911.
Quarry Act, 1894.
Merchant Shipping Act, 1894.
Notice of Accidents Acts, 1894 and 1906.
Railway Employment (Prevention of Accidents) Act, 1900.

The effect of these statutes is:—

(1) To impose upon the owners of all steam boilers and vessels subject to an internal pressure duties with regard to the notification of explosions and accidents to the Board of Trade, and to make provision for inquiries and investigations into the causes and circumstances of such explosion or accident.

(2) To make compulsory the provision of certain safety appliances upon boilers used in mines, quarries, ships, factories and workshops, and on railways, and to regulate the inspection of boilers in factories and workshops and on board ship.

(1) Notification of Explosions and Board of Trade Inquiries.

The most important statutes affecting all steam users are the *Boiler Explosions Acts,* 1882 *and* 1890. The Act of 1882 was enacted to provide "for making inquiries with respect to boiler explosions" in certain cases, and the amending Act of 1890 extended the provisions of the earlier Act to all boilers wherever they may be *except* those "used in the service of Her Majesty" or "used exclusively for domestic purposes."

The term "*boiler*" by this Act means any closed vessel "used for generating steam or for heating water or for heating other liquids or into which steam is admitted for heating, steaming, boiling or other similar purposes." It will, therefore, be seen that all hot water or steam heating apparatus, drying tables, kiers, ovens heated by sealed tubes, economisers, engine cylinders, steam jackets and steam pipes, and the like—are included within the provisions of the above Act. In *Reg.* v. *Boiler Explosions Commissioners*, [1891] 1 Q. B. 703, "boiler" as defined by section 3, Boiler Explosions Act, 1882, was held to include a valve in a steam pipe which was in fact 1,300 feet away from the boiler. It was held also in that case that explosions of boilers in mines were within the Act of 1882 as amended by section 2 of the Act of 1890.

The exception "*exclusively for domestic purposes*" has been the subject of judicial interpretation in *Smith* v. *Muller,* [1894] 1 Q. B. 192. This was a case stated by the

Stipendiary of Birmingham to the Divisional Court, Charles and Wright, JJ. The respondent was summoned by the appellant on behalf of the Board of Trade for having made default in complying with the requirements of section 5 of the Boiler Explosions Act, 1882. For the respondent it was claimed that the boiler in question was within the exception of section 4 of the Act. The boiler which exploded was used for circulating hot water through a range of piping which warmed the office of the respondent's clerks only. The office was used for the purpose of the respondent's business. There was a tap fixed in the boiler to supply warm water for cleaning the offices and for other household purposes of the caretaker.

It was held that the above boiler was used exclusively for domestic purposes. Charles, J. said, "The test made applicable by the statute is not the character of the persons using the boiler, not whether they occupy or reside upon the premises, but the use made of the boiler." He added, however, "It is said to be difficult to draw the line if residence is not the test: the answer is that in these cases the line must be drawn by somebody and that it is a question of fact for the tribunal before which the case comes whether the boiler is used exclusively for domestic purposes."

Section 5 *of the Act of* 1882 provides that on the occurrence of any explosion of any boiler to which the Act refers, the owner or user shall send notice of such explosion within twenty-four hours of the occurrence to the Board of Trade (for particulars to be contained in such notice see Appendix A., p. 102). Upon receiving such notice the Board of Trade may appoint one or more engineers to make a preliminary inquiry with respect to the explosion. Wide powers are given to such engineers to inspect the exploded boiler and to examine and require answers under oath from all such persons as they think fit to summon before them.

The engineer or engineers making this preliminary inquiry will make a report to the Board of Trade which, either with or without such preliminary inquiry (in practice always with such inquiry), may if it thinks expedient direct a formal investigation to be held into the cause and circumstances attending the explosion. Such investigation will be made by a Court consisting of two or more Commissioners appointed by the Board of Trade (one at least a competent and practical engineer specially conversant with the manufacture and working of steam boilers, and one a competent lawyer), who will make a report to the Board of Trade stating whether they consider any person or persons to blame for the explosion. The Court has power to order any person or persons they find so to blame to pay such costs of the preliminary inquiry and formal investigation as they think fit.

The powers of the court of investigation, the form of procedure, and precedents of its judgments, are dealt with fully in section 2.

Notification of explosions and accidents and Board of Trade inquiries and investigations are concurrently provided for by other statutes in special cases:—

The Notice of Accidents Act, 1894, *and the amending Act*, 1906, require that notice of accidents occurring in the construction, use, working or repair of any railway, tramroad, tramway, gasworks, canal, bridge, tunnel, harbour, dock, port, pier, quay, or other work authorised by any local or personal Act of Parliament; or in the construction or repair by means of a scaffolding of any building which exceeds 30 feet in height, or use or working of any such building in which more than twenty persons, not being domestic servants, are employed for wages; or in *the use or working of any traction engine or other engine or machine worked by steam in the open air*, shall

be sent to the Board of Trade if they cause any person employed either loss of life or such bodily injury as to cause him to be absent throughout at least one whole day from his ordinary work. The Act further provides for formal investigations to be held into the causes and circumstances of the accident if the Board of Trade thinks fit.

In Factories or Workshops.—Section 4 of the Notice of Accidents Act, 1906, repealing section 19 of the Factory and Workshop Act, 1901, requires written notices to be sent to the inspector of the district of any accident causing loss of life; or if the accident is due to any machinery moved by mechanical power, or to molten metal, hot liquid, explosion, escape of gas or steam, or to electricity, so disabling any person employed as to cause him to be absent throughout at least one whole day from his ordinary work; or any accident whatever disabling any person employed from working at his ordinary work for more than seven days. If the accident causes loss of life or is produced by machinery or an explosion, notice must also be sent to the certifying surgeon of the district.

Section 22 of the Factory and Workshop Act gives the Secretary of State power to direct that a formal investigation be held into the causes and circumstances of such accident.

On Railways.—Section 6 of the Regulations of Railways Act, 1871, requires notice to be sent to the Board of Trade by the earliest possible post after the occurrence of any accident attended with loss of life or personal injury, or likely to cause loss of life or personal injury to any person.

Section 7 of the same Act gives the Board of Trade power to order an inquiry and formal investigation into the cause and circumstances of the accident.

On Ships.—The Merchant Shipping Act, 1894, s. 425, requires notice to be sent within twenty-four hours or as soon thereafter as possible of any accident occasioning loss of life or serious personal injury or material damage affecting the ship's seaworthiness or efficiency either in hull or machinery. Sections 465 and 466 give the Board of Trade power to direct a preliminary inquiry and formal investigation into any "shipping casualty" which includes, by section 464, "when any loss of life ensues by reason of any casualty happening to or on board any ship on or near the coast of the United Kingdom." The court of investigation in this case will consist of a Court of Summary Jurisdiction with the assistance of one or more assessors.

In Mines and Quarries.—The Coal Mines Act, 1911, s. 80, and the Notice of Accidents Act, 1906, amending section 11 of the Metalliferous Mines Regulation Act, 1872, require notice to be sent to the inspector of the district of any accidents to any person employed in or about a mine or quarry which causes loss of life, fracture to the head or limb, or any dislocation of a limb, or any other serious personal injury, or which is caused by any explosion and causes any personal injury whatever.

Sections 82 and 83 of the Coal Mines Act provide for inquiries and formal investigation of any such explosion or accident occurring in a coal mine, while section 20 of the Metalliferous Mines Regulation Act provides for a special report to be made by the district inspector "with respect to any accident in a mine to which the Act applies which accident has caused loss of life or personal injury to any person." The Quarries Act, 1904, makes this section applicable to quarries. It should be observed that although a quarry is a "factory" within the provisions of the Factory and Workshop Act, the provisions in

that Act in regard to the notification of accidents do not apply (see Quarry Act, s. 3).

(2) Compulsory Provision of Safety Appliances and Periodical Examination.

(*a*) **In Factories, Workshops and Certain Mines.** — The Factory and Workshop Act, 1901, s. 11, and the Coal Mines Act, 1911, s. 56 (Appendix E., pp. 125, 126), make compulsory the periodical examination of all steam boilers "used for generating steam" in factories, workshops and in mines of coal, stratified ironstone, shale or fireclay. Such boiler must be examined thoroughly by a "competent person" at least once in every fourteen months, and a report of the result of such examination made upon a prescribed form (see p. 124) and attached to the register of the factory or to a book kept in the mine for the purpose. These sections also enact that such boiler shall have attached to it "a proper safety-valve and a proper steam gauge and water gauge to show the pressure of steam and the height of water in the boiler," which appliances shall be "maintained in proper condition."

In addition to these provisions the same section of the Coal Mines Act prohibits the placing of any steam boiler under ground, and provides that all water gauges shall have a covering or guard "unless so constructed as to be equally safe to the persons employed whether so protected or not."

It will be observed that the definition of a boiler under the provisions of both these Acts is confined to those "used for generating steam," and does not therefore include all vessels subjected to internal pressure. Vessels into which steam is admitted, *e.g.*, drying tables, kiers, engine cylinders, steam jackets, and steam pipes, are not used for generating steam. These are, therefore, undoubtedly out-

side the Act. Certain other vessels subjected to internal pressure do not generate steam under normal conditions, but at the same time are capable of becoming subject to a self-generated steam pressure under exceptional circumstances (*e.g.*, economisers, hot water supply boilers, &c.). It is submitted that these vessels also are not included in the above definition, because it would be impossible to fit a water gauge to such vessels as are always full of water, and hitherto no steps have been taken to make the provision of the above Act applicable. On the other hand, it has frequently been pointed out by the Commissioners that for the purposes of safety such vessels should be provided with a safety-valve and pressure gauge, and they have recommended the extension of the above Act to all vessels subject to steam pressure, whether used for generating steam or not.

With regard to the type of safety appliance which may be considered "proper," it would appear that if the steam gauge shows the correct pressure and the water gauge the correct height, no exception can be taken to them whatever the type. In regard to the safety-valve, there is less definite enactment, but it should be observed that the engineer in chief to the Board of Trade has characterised a spring balance safety-valve capable of being screwed down as "most objectionable" (80).

The maintenance of safety appliances in a "proper condition" is dealt with in section 3, pp. 39—43.

The periodical examination must be made by a "competent person." Such a person is not defined in the Act, but in the administration of the Boilers Explosions Act the Commissioners have on several occasions held an owner to blame for engaging an incompetent person to make examination of his boiler. In one case a relative of the owner, a fitter, eighty years of age, who had received no

training as a boiler inspector (1538), and in another case a boiler repairer who knew nothing of the manner in which boilers ought to be tested (1589), were held to be incompetent. In both these cases, however, their competency was tested by their mode of examination, and perhaps this provides the best test of all of a "competent person." On the back of the prescribed form upon which the result of an examination under the Factory Act must be made will be found the proper and satisfactory mode of examination of a boiler, and if any person with a knowledge of boiler construction and working conforms with these rules, he will, it is submitted, be considered a competent person (the form will be found in Appendix E., p. 123). Boiler insurance companies, who give a guarantee of safe working of a boiler, engage a very efficient staff of inspectors for their own protection, and the owner who engages an insurance company to make an inspection in compliance with this Act has the additional security of having the report of the examination counter-signed by the chief engineer of the company (see sub-section 3, pp. 125, 127).

Section 17 of the Factory and Workshop Act and section 108 of the Coal Mines Act, give power to a Court of Summary Jurisdiction to prohibit the use of machinery including boilers, &c., if on the report of the inspector the Court is satisfied that it is dangerous.

Section 79 of the Factory and Workshop Act gives power to the Secretary of State to make regulations for the use of dangerous machinery and plant. Under this section the following regulations applicable to steam plant have been made:—

(*a*) No person under eighteen shall be employed as a locomotive driver.

(*b*) All glass tubes of water gauges on locomotives or stationary boilers used for the movement of waggons shall be adequately protected by a covering or guard.

A *Quarry* is a "factory" under the provisions of the Factory and Workshop Act, 1901, Sch. 6, s. 26, and is therefore subject to all the above provisions with regard to safety appliances and inspection.

(*b*) **On Ships.**—The Merchant Shipping Act, 1894, s. 285, sub-s. 4, requires a passenger steamer to be provided with a safety-valve on each boiler, so constructed as to be out of the control of the engineer when the steam is up, and if the safety-valve is in addition to the ordinary valve, so constructed as to have an area of not less and a pressure not greater than the area of and pressure on the ordinary valve.

Sections 271 and 272 require a steamship carrying more than twelve passengers *to be surveyed at least once a year*, and require every passenger ship before proceeding to sea to obtain a certificate from the Board of Trade stating (*inter alia*) (1) that the safety-valves are such and in such condition as required by the Act, and (2) the limit of weight to be placed on the safety-valve.

The Board of Trade have drawn up "Regulations and suggestions as to the survey of the hull, equipment and machinery of steamships" and those which refer to boilers are commonly referred to as the "Board of Trade Boiler Rules." These rules provide such an important test of the condition and safety of a boiler that the provisions of the most important have been referred to throughout this work.

(*c*) **In Metalliferous Mines.**—The Metalliferous Mines Regulation Act, 1872, s. 23, r. 18, requires that all steam boilers used in mines shall be provided with a proper steam gauge, water gauge and safety-valve. A "mine" includes shafts and inclined planes in the course of being

SUMMARY OF OFFENCES AGAINST STATUTORY OBLIGATIONS AND PENALTIES.

Offence.	Page reference.	Penalty not exceeding.	Statute reference.
1. *All boilers as defined by Boiler Explosions Act, 1882*—			
Failing to give notice of explosions.	3	Twenty pounds.	Boiler Explosions Act, 1882, s. 5.
Being found to blame for the explosion.	4	Costs of preliminary inquiry and formal investigation.	Section 7.
2. *Boilers on Railways*—			
Failing to give notice of accident.	5	Twenty pounds	Regulations of Railway Act, 1871, s. 6.
3. *Boilers in Ships*—			
Failing to give notice of accident.	6	Fifty pounds	Merchant Shipping Act, 1894, s. 425.
Failure to provide safety-valves.	10	Owner, £100 Master, £50	Section 285.
Safety-valve not out of control of engineer when steam is up.	10	Owner, £100 Master, £50	Section 285.
Putting undue weight on safety-valve.	41	£100	Section 433.
Weight on safety-valve of passenger ship increased above that fixed by the surveyor.	41	£100	Section 286.
4. *Boilers in Mines or Quarries*—			
Removing or damaging safety-valve.	—	Agent or Owner-Manager, £20. Other person, £2.* If Inspector has given notice, £1 extra each day.	Met. Mines Regulation Act, ss. 23, 31. Coal Mines Act, ss. 56, 80, 101. Quarry Act, 1894, s. 2. Notice of Accidents Act, 1906.
Failing to give notice of accident.	6		
Failing to provide safety-valve, steam gauge and water gauge.	7 10		
[illegible] have [illegible]	7		
5. *Boilers in Factories, Workshops or Quarries*—			
Neglecting to have boiler examined.	7	£10, but if any person is killed or injured, £100.	Factory and Workshop Act, 1901, ss. 11 and 135 (see also sections 141 and 142).
Failing to provide safety appliances.	7		
Contravention of order made by magistrate.	9	40*s.* a day during contravention.	Section 17.
Locomotive driver under eighteen.	9	Manager, Owner or Occupier, £10, and £2 a day during continuance. Other person, £2.	Sections 79 and 85.
Water gauge not adequately protected.	9		
Failing to give notice of accident.	5	£10.	Notice of Accidents Act, 1906, s. 4.

* In coal mines this penalty is £5, and if the act is wilful and such as to endanger the safety of persons employed, imprisonment without the option of a fine.

sunk or driven, and all works and tramways above and below the ground adjacent to the mine.

Special regulations* have also been issued (varying slightly in different districts) for the safe working and periodical inspection of boilers in mines within this Act.

(*d*) **On Railways.**—The Prevention of Accidents Rules, 1902, made by the Board of Trade pursuant to section 1 of the Railway Employment (Prevention of Accidents) Act, 1900, contain the following applicable to steam plant.

6. All boiler gauge glasses on locomotive engines or on stationary steam boilers used in the working of railways must, within three years from the coming into operation of these rules, be protected by a covering or guard sufficient to guard against accident to persons employed on the railway through the gauge glasses breaking.

7. All tool boxes used for the purpose of storing tools and other things, necessary in the working of locomotives when running, must, within two years from the coming into operation of these rules, be so arranged that the contents may be obtained by the men while the engine is in motion without undue risk of injury.

Water gauges or similar devices must, within three years from the coming into operation of these rules, be provided on locomotive engines or tenders to indicate the amount of water in the tanks, and such gauges and similar devices shall be placed in such a position as to be visible and accessible to the men without their incurring undue risk of injury.

* See "Codes of Rules in force in Mines and Quarries in the United Kingdom."

SECTION 2

FORMAL INVESTIGATIONS AND FINDINGS OF COMMISSIONERS AS TO NEGLIGENCE

THE powers of a Court appointed by the Board of Trade to hold a formal investigation are defined by section 6, sub-section 4, of the Act of 1882 (see Appendix A., p. 100).

It will be seen that the Court has all the powers of a Court of Summary Jurisdiction, and in addition may enter and inspect any place it may think necessary; it may summon before it and examine any such persons, and require them to make answers to any inquiries, it thinks fit; it may require the production of books, papers and documents it thinks important and it may administer an oath.

The Court is composed of not less than two Commissioners, one of whom is a competent and practical engineer, and the other a competent lawyer. It is usually presided over by the lawyer, who generally is an experienced barrister.

Persons summoned to the Court.—It appears from the practice of the Board of Trade that the persons summoned before the Court are all those persons who may in any way be responsible for or may have contributed to the explosion. In addition the Court sometimes summons persons who can give it assistance in arriving at the correct circumstances attending the explosion. Invariably the owner or user of the boiler is summoned, and in addition the manager for the user, the foreman supervising the boiler

attendants, and the boiler attendants themselves. If there be any possibility that the explosion is due to defective design, workmanship or material in the construction of the boiler, the maker is summoned before the Commissioners, whilst if the explosion can have been due to lack or inefficiency of inspection, the person who inspected or was responsible for inspection, or in the case of an insurance company, the chief engineer or one of his inspectors, is usually summoned.

The summons goes out in the name of the Commissioners, but the decision as to upon whom it should be served is a matter for the discretion of the Board of Trade acting through one of its assistant solicitors, no doubt informed of all the details of the explosion by the Board of Trade engineer who held the preliminary inquiry. The Commissioners may also issue further summonses at the time of the investigation. A copy of the form of summons will be found on p. 123. It will be seen that on the summons attention is drawn to the provisions of section 7 of the Act which gives the Commissioners power to order any person summoned before them to pay the costs of the investigation.

With the summons is sent also a list of questions which the Board of Trade propose to ask the Commissioners to answer. These questions, of which many precedents may be found in the Board of Trade reports, usually include a question asking the Commissioners to say whether certain persons (named) are to blame for the explosion, and if so whether they should pay any of the costs of the investigation. Any person summoned before the Court is therefore prepared by the form of summons and the copy of questions for the issues to be decided.

The Commissioners themselves come to the investigation with open minds. They do not see the report of the pre-

liminary inquiry made by the Board's engineer, and until he is called into the witness-box receive no intimation as to what theory of the cause of explosion has been formed.

Procedure at the Investigation.—At the opening of the Court the presiding Commissioner will usually read the appointment of the Court by the Board of Trade. The solicitor appearing for the Board of Trade (a member of the Board's legal department) will then briefly state the facts of the explosion, and he will call before the Commissioners all those witnesses who have been summoned to give evidence. His questions are usually directed with a view to placing before the Court the history of the boiler, the details of management and the incidents immediately preceding the explosion. Any person summoned to the Court may then examine the witness, either by legal representative or in person. The Commissioners will then usually ask questions of the witness. These questions very often appear in the form of cross-examination, because it is for the Commissioners to decide who is to blame for the explosion.

After the solicitor to the Board of Trade has called those persons summoned to the Court, he will call the Board of Trade engineer or engineers who made the preliminary inquiry, and will question him or them as to the cause of the explosion. In cases where the cause is obscure, the Board's solicitor may call additional expert evidence. Any person summoned to the Court may then cross-examine the Board of Trade witnesses, and it will be open for him to call and examine expert witnesses to rebut the evidence of the Board's experts, who will in turn be cross-examined by the Board of Trade solicitor. The Commissioners also will cross-examine such witnesses.

After all the evidence has been called, the solicitor to the

Board of Trade will give to the Court the questions which he requires the Commissioners to answer. Any of the parties may then address the Court, and the Board's solicitor may reply. In giving their judgment, the Commissioners will usually detail the events leading up to the explosion, express their opinion as to the cause of explosion, say if any and what persons are to blame, and make any order (if any) they think fit with regard to the payment of costs by those whom they find culpable.

The Act provides that the formal investigation "shall be made at or near the place of such explosion." It is usual for it to be held in some convenient room or Court in the nearest town or village. This will enable the Commissioners to make an inspection of the site of the explosion during or before the investigation. Such inspection will give them a clearer idea of the manner in which the management of the boiler was conducted, and if the boiler has been left in the position it was in after explosion, the Commissioners may be able to gather facts to assist them in coming to the correct conclusion as to the cause of the explosion. The investigation, however, is very often held months after the explosion, and the boiler is rarely left undisturbed over the intervening period.

The Findings of Commissioners as to Negligence.

"Boiler explosions are never attributable to inevitable accident" (*vide* Commissioners' reports).

Besides the duties imposed by statute upon the owners of boilers, there is a duty on the part of the owners, their servants, boiler-makers, repairers, vendors and insurance companies, to use reasonable care in the management, manufacture, repairs and inspection of boilers.

The following pages deal with the duties of these

persons and enumerate the grounds upon which persons have been held to blame by the Commissioners.

(*a*) **Duty of the Owner.**—"Owners are responsible for the efficiency of their boilers and plant and for the exercise of adequate supervision during their use" (1700).

These duties may be divided:—

(i.) As to boiler attendants and supervision.
(ii.) As to safe working pressure; and
(iii.) As to inspection.

(i.) **Boiler Attendants and Supervision.**—It is the duty of the owner to have competent attendants upon the boilers and careful supervision of the men. The legislature has not laid down any particular requirements as to the qualifications of a boiler attendant, and it is not necessary that he should have any special qualifications other than intelligence to understand the duties required of him. The most essential quality in such a man is reliability, as negligence so often leads to disaster.

If the owner engages competent men properly instructed for their work, and adequately supervised, he will not be responsible for acts or omissions by them which cause explosion. The Commissioners said in report 1624:—

> "At Common Law an employer is liable for the acts of his servants in the ordinary course of their duties, but we do not think that is a test under the Boiler Explosion Acts. These Acts we consider were intended to affect those only who are morally to blame for not taking proper precaution, and so act as a deterrent to others and thus prevent neglect in the management of boilers."

On the other hand, for failure to give proper instructions to his employees that they were not to make joints while the boiler was under pressure (1609) or for the negligent supervision of a foreman in adjusting a safety-valve (1169)

or for leaving the control of large works in the hands of an unqualified manager (1607) or an unqualified engineer without efficient superintending inspection (1492), owners have been held to blame.

The owner must work his men reasonable hours. A manager was found to blame for allowing a fireman to work continuously for $34\frac{1}{2}$ hours, so causing him to neglect his duty (1686).

(ii.) **Safe Pressure.**—Further it is the duty of the owner to work his boiler at a safe pressure (1668). He is not entitled to take the opinion of an incompetent engineer on this matter, nor must he trust to his own experience unless he is a qualified or trained engineer.

Very many cases are reported in which owners have been found to blame for using unsafe boilers or plant without taking the advice of a competent engineer. So where pressure was too great and the safety mountings inadequate (1555), or where an explosion occurred through a stop-cock on a kier being placed so that it could be tampered with, and no competent advice had been taken or inspection made, the owners were held to blame. In one case (1127) the owner was blamed for using an unsafe cylinder which was a duplicate of one he had used in his works, but which he designed and ordered without consulting a competent engineer or informing the manufacturers of the pressure at which it would be worked.

The owner is also required to keep his boiler in good repair and to shut down the boiler when a defect appears (1699). On the other hand, in one case where the leak was believed to come from the seam, although in fact it was through an angle iron, the Commissioners said:—

"Having regard to the nature and position of the crack it would not be unreasonable, in fact it would be natural, for the boiler-maker to think that the leak came from the seam, and we cannot find that

there was negligence in allowing the boiler to be worked for a short time until another boiler was ready to take its place, as a slight leak from the seam could not be taken to indicate any immediate danger" (1,493).

After repairs have been executed the owner ought to have his boiler tested by hydraulic pressure (1485) or take the advice of an insurance company or other competent boiler engineer.

(iii.) **Inspection.**—In factories, workshops and mines the inspection of boilers used for generating steam is now controlled by law (see *ante*, p. 7). Such boilers must be examined every fourteen months and a report made on the prescribed form, and attached to the general register of the factory or workshop.

There is, however, a duty on all owners as users of boilers, whether under the Factory Act or not, to have their boilers examined periodically by a competent person. In particular it has been held to be gross negligence to instal a second-hand boiler without such previous inspection (1349), whilst working a boiler beyond a reasonable time without further inspection has been held to be negligence (1405). The "reasonable time" has not been specifically stated, but in report 1524 (see p. 20) a year was held to be an excessive period when the boiler was fed with canal water. In case 1382 the owner had not had the boiler examined for over six years and he pleaded ignorance of the necessity for examination. The Commissioners said:—

"Although in this case there has been no loss of life, boilers cannot be worked under like conditions without the gravest risk. We repeat what we have said on many other occasions, that a steam user cannot be heard to say as an excuse for mismanagement of a boiler that he was ignorant as to what he ought to have done. If he were to take the trouble to think about the matter at all he must know, or he must be taken to know, that boilers, like

other things, will wear out, and whether they are wearing out or not can only be ascertained by examination."

The person whom the owner engages to examine the boiler must be competent. Very many cases are reported where the owners have set up as a defence the negligent examination by some incompetent person (1492), and severe penalties have been inflicted on persons who, for the purposes of the Factory Act, have engaged incompetent persons to inspect the boiler (1538), (1589).

The advice of a competent engineer does not dispense with the duty of periodical inspection. Where an owner purchased a boiler from a reputable firm, by whom it had been recommended for a pressure of 50 lbs., the Commissioners said that he was justified in using the boiler for a considerable time without examination, but it ought to have been examined within two years (1337). [This boiler was not under the Factory Act.]

When the boiler is insured by an insurance company which gives a guarantee of safety or inspects for the purpose of the Factory or Coal Mines Act, the owner is relieved from the responsibility of inspection and safety (but not from his duty to have some competent person in charge (969)), provided that he carries out all the instructions and acts upon the advice of the company and gives them all facilities for making their periodic inspection, and unless the conditions under which the boiler is worked make more frequent examinations imperative. In report 1588 the Commissioners said:—

"The owners of machinery are not entitled in our opinion to shelter themselves behind any report of an insurance company's inspector unless they have carried out to the full, not only what the insurance company *insists* upon, but also what the insurance company *may recommend*. . . . Insurance companies cannot very well insist upon too much; they cannot make their conditions too

stringent, otherwise they would lose their business . . . but if owners of machinery . . . wish to get a complete protection for themselves and a complete absolution for anything that may be done with regard to that machinery, they must do everything the insurance company recommends."

In report 1842 the Commissioners held the owners to blame for an explosion due to deposit on the water tubes, owing to neglect in cleaning as advised by the insurance company. They said:—

"Though the advice may have come from a doubtful mind we think it is sound and not to be ignored by men who are not engineers themselves."

Where an insurance company advises hydraulic tests, it is the duty of the owner to have such tests carried out unless he has good reason to the contrary (1254), (1588).

Where an inspector condemned the boiler as unsafe and the owner continued to work it, he was found guilty of gross neglect (1541).

In spite of warning from insurance company of the necessity of keeping grease out of the boiler and tubes, the owners did not use adequate measures to keep it clean (1701), and were held to blame.

For concealing facts of management likely to be dangerous from an insurance company (454), and not properly cleaning the boiler for inspection (1438), owners and their managers were held to blame.

In report 1524 of a case in which canal water was used to feed the boiler, it was urged on behalf of the person in charge of the boiler that he thought it had been passed by an inspector of an insurance company within a year of the explosion. The Commissioners said:—

"The general practice of insurance companies, we believe, is to examine a boiler thoroughly at least once a year, and to partially examine it, that is examine it externally, at intervals during the year. With regard to many boilers, no doubt this examination

once a year is sufficient to ensure safe working during that period. But when a boiler is subject to conditions which render more frequent examinations imperative, as this one was, it is manifest that unless notice of the fact is given to the insurance company and other examinations asked for, owners cannot relieve themselves of the responsibility of making independent examinations."

(*b*) **Duty of Insurance Companies and their Inspectors.**— The position of insurance companies depends upon the form of insurance. Most insurance companies who specialise in boiler insurance give guarantees as to the safety of the boiler, and by a system of periodic inspection satisfy the requirements of the Factory and Coal Mines Acts. Other insurance companies, however, may insure a boiler as one of the incidental risks of a general insurance, and in this case, do not give any guarantee to the owner that his boiler is safe.

Although the Commissioners have very strongly condemned the action of an insurance company which insures a boiler without proper inspection, unless the insurance company has given some guarantee of safety or has undertaken inspection under the Factory Acts, there is no legal compulsion upon it to inspect. In report 382, the Commissioners said:—

"We pointed out during the course of the investigation that an insurance company may insure a boiler whatever its condition may be. The contract of insurance is between the insurer and the insured. The insurers have no duty as far as we know, by statute or otherwise, cast upon them with regard to the safety of the public or the employees of the insured. We cannot therefore say that they are to blame for the explosion, but we do think, in the interests of human life and as a safeguard against insurances which may be effected by careless or immoral owners, that they should satisfy themselves by careful examination that the boiler they contemplate insuring is as safe as it can be, that is to say, that it would be safe to work it at the pressure which their policy is going to allow. We express the hope that they will adopt this

course in the future. . . . It has been suggested that owners are lulled into a false sense of security by the inspection of boilers made by insurance companies even when they are only superficial, because it is said that the owner would say to himself, " my boiler must be safe or else the company would not take the risk." We are disposed to think that this may be so in some instances, and therefore think that it would be well for a company before it takes the risk to bring to the attention of the owner that it does not by so doing guarantee the safe working of the boiler at the pressure which the policy may allow. If this were done there would not be any pretence for the suggestion of the owner that he was by the company's acceptance of the risk in any way relieved from moral responsibility as to the condition of the boiler."

In report 456 the Commissioners made stronger comment upon the action of an insurance company insuring without inspection, saying:—

"We do not think he (the insurance company's engineer), having due regard to the interests of human life, was justified in entering into the insurance without making a proper inspection of the boiler, although legally he was justified in so doing."

Where an insurance company guarantees the safe working of a boiler, or undertakes the inspection required by the Factory Acts, it is in a different position, and may be held to blame for improper or careless inspection.

In one case an insurance company issued a certificate as required by the Factory Acts without having made a proper inspection (1638). The insurance company was held liable for the explosion and the chief engineer and district inspector were both severely blamed and fined by the Commissioners for having issued a false certificate. Several other cases are reported in which the insurance company has been held liable for the neglect of their inspector in failing to find serious defects in the boiler (969), (1254), (1718), and for neglecting to have the brickwork removed so that proper inspection might be made (1689). In

the last case, where the engineer of the insurance company contended that it was in a commercial sense impossible to expect a client to go to the expense of removing the brick-work, and that he would not require the brickwork to be removed unless there was something suspicious to warrant such a requirement, the Commissioners said:—

"An insurance company's engineer, as a competent person under the Factory Acts, in issuing a certificate, ought to exercise his judgment as an engineer, apart from the policy of the company. The policy of a company not to require brickwork to be removed unless there is either dampness or suspicion of defects is not, in our judgment, a sound one, certainly not as regards the safety of the public, although it may be a good policy."

An insurance company which undertakes the inspection of a boiler must warn the owner of any defects. This must be done in no uncertain manner. Where a company wrote that the condition of the boiler was "serious" when it was in fact "very serious," it was held that the warning was not sufficient and the company were blamed (456), and in report 1438, where the owner mistook a letter from the boiler insurance company to be a letter of acceptance of a risk when it was in fact only a conditional acceptance, and so worked his boiler at an excessive pressure, the Commissioners said:—

"We desire to point out that insurance companies and others reporting upon the condition of a boiler should express themselves in the plainest terms which cannot be mistaken by ordinary individuals."

Where an insurance company's inspector failed to call attention to grave defects in water gauge fittings and inefficient feeding arrangement, he was blamed though no order was made against him (1601).

(*c*) **Duty of other Persons inspecting Boilers.**—Engineers

or persons professing knowledge of boilers, who inspect the boiler for the owner, either for the purposes of the Factory Act or to test its safety, must use the same care in inspecting the boiler and warning the owner as an insurance company. The Commissioners have often severely censured persons who have wrongly advised the owner as to safe working pressure while professing technical knowledge (1152), or who have inspected the boiler for the owner and have failed to make a proper inspection; in not withdrawing stays to ascertain their condition (1328); in not probing locomotive tubes to test for corrosion (1349); or in not warning the owner of the dangerous practice of gagging the safety-valve (1378).

A firm of economiser manufacturers was found to blame for adopting and approving a system of examination which omitted to remove the caps from the tubes, thereby failing to detect a corroded bolt (1371). A firm of engineers was also held to blame for the neglect of a boiler-maker whom they sent to examine the boiler in his not discovering that the fire-box was in a dangerous condition on account of its being deprived of the support of one of its stays (1309). For allowing a boiler of his client in a metalliferous mine to be worked in a dangerous condition contrary to the rules of management of such mines, a consulting engineer was severely blamed (575).

(*d*) **Duty of the Makers or Repairers of the Boiler.**—The duty of the maker is to provide a boiler of good design, material and workmanship. Where makers supplied a heating apparatus of defective design (865) or a casting which they knew to be defective (1567), and where the workmanship was faulty in giving rise to incipient flaws (1699), they were held to blame. In the last case they were ordered to pay additional costs because they tried to lay the

blame on the suppliers of the material which the Commissioners found to be sound.

It is also the duty of the maker to give the safe working pressure of the vessel (1567), and in several cases makers and vendors have been held to blame for misrepresentation in this respect (1347).

A firm of engineers were held grossly to blame for selling a corroded boiler and representing it to be in a good condition and fit for a working pressure not exceeding 60 lbs. (1473).

Similarly a repairer must make good repairs, and he must point out any other defects in the boiler which ought to be repaired (1137), (1170), (1328). A firm of boiler-makers who carried out the rearrangement of piping which was without proper support was held to blame (1609).

(*e*) **Duty of other Persons.**—All boiler attendants and foremen must exercise reasonable care in the carrying out of their duties. For various acts of negligence workmen have been fined, and also for gagging the safety-valve (355) [which offence is now punishable by statute in certain cases (see *ante*, p. 11)]. A bricklayer has been fined for setting the boiler on common instead of fireclay bricks (1351).

Fines.—The amount of costs ordered to be paid by the Commissioners has varied from £2 in the case of an attendant to £400 in the case of a manufacturing firm. It does not appear to depend upon the amount of damage or loss of life occasioned (several cases having been investigated where no personal injury was done (538)), but rather upon the degree of negligence and the financial position of the defaulter. In many cases the Commissioners have said that they would have imposed a far greater penalty had it been possible to recover the amount from one in the circumstances of the person so fined. The Commissioners

have greatly mitigated the fine imposed upon an owner who has made generous provision for the dependants of the persons killed (431), and in several cases they have made no order because the defaulter has himself been seriously injured in person or in financial position.

The fines are recoverable by summons before a Court of Summary Jurisdiction and have in several instances been the subject of a conviction.

SECTION 3

THE CAUSE AND PREVENTION OF EXPLOSIONS

UNDER the Boiler Explosions Act the term "explosion" is not defined, but it will be seen from the reports since 1882 that the term has been taken to include any sudden outrush of steam or water and any sudden bulging or collapsing of a furnace or flue, whether causing loss of life or not. Mr. Michael Longridge, Chief Engineer of the Engine Boiler and Electrical Insurance Company, in the diagram reproduced, by his permission, on p. 30, from his annual report for 1911, shows the annual number of explosions, collapses and mishaps on land and afloat up to 1910.

From the same report the tables on pp. 28 and 29 are reproduced by his permission. They give (1) the numbers of explosions, collapses and mishaps reported on by the Board of Trade, and the total and average number of deaths resulting therefrom during the twenty-seven and a half years ending December, 1909, with the corresponding figures for the year 1910; and (2) the description of the boilers which have exploded or collapsed during the twenty-eight and a half years from June, 1882, when the first Boiler Explosions Act came into operation, to December, 1910, and the causes of these explosions and collapses.

NOTE ON WORKING STEAM PRESSURE, BREAKING AND SAFE STRENGTH OF METALS, AND FACTOR OF SAFETY.

A boiler under working conditions is a vessel which is subjected to steam or other pressure, and must therefore be

TABLE 1.

	Up to end of 1909.				During 1910.	
	Numbers.		Deaths.		Numbers.	Deaths.
	Total.	Average.	Total.	Average.		
Explosions of land boilers	257	9·4	184	6·7	8	0
Collapses of fire-boxes and flues of land boilers	308	11·2	151	5·5	5	1
Explosions afloat	21	0·8	17	0·6	0	0
Collapses afloat	125	4·6	38	1·4	2	2
Sundry mishaps on shore	615	22·4	210	7·6	58	4
Sundry mishaps afloat	524	19·1	112	4·1	30	5
Explosions of boilers used for heating buildings	61	2·2	7	0·3	2	0
	1,911	69·7	719	26·2	105	12
Among these the following were insured by boiler insurance companies* :—						
Explosions	54	2·0	55	2·0	6	0
Collapses	86	3·1	45	1·6	3	1
Mishaps	158	5·8	33	1·2	9	0
	298	10·9	133	4·8	18	1

* Not including boilers insured by marine and accident insurance companies.

TABLE 2.

Type of Boiler.	Land Boilers. Number of Explosions.	Land Boilers. Number of Collapses.	Boilers Afloat. Number of Explosions.	Boilers Afloat. Number of Collapses.
Plain cylindrical	68	0	0	0
Locomotive and portable	43	37	0	2
Cornish	40	66	0	0
Vertical, with internal fire-box	25	154	8	35
Lancashire	20	32	0	0
Galloway	0	10	0	0
Chimney	1	6	0	0
Marine	1	0	5	77
Return flue	0	0	7	10
Water-tube	15	0	1	0
Multitubular, externally fired	1	0	0	0
Miscellaneous	25	4	0	3
Hot-water	89	4	0	0
	328	313	21	127

Cause of Explosion or Collapse.	Land Boilers. Number of Explosions.	Land Boilers. Number of Collapses.	Boilers Afloat. Number of Explosions.	Boilers Afloat. Number of Collapses.
Corrosion	106	150	11	18
Grooving	29	4	0	0
Excessive pressure	33	27	3	9
Outlets frozen	70	4	0	0
Failure of stays	15	13	0	4
Deficiency of water	19	68	0	53
Structural weakness	15	29	1	4
Fractures	14	2	0	0
General deterioration	5	0	4	0
Seam rips	7	0	0	0
Deposit	13	12	0	35
Not ascertained	2	4	2	4
	328	313	21	127

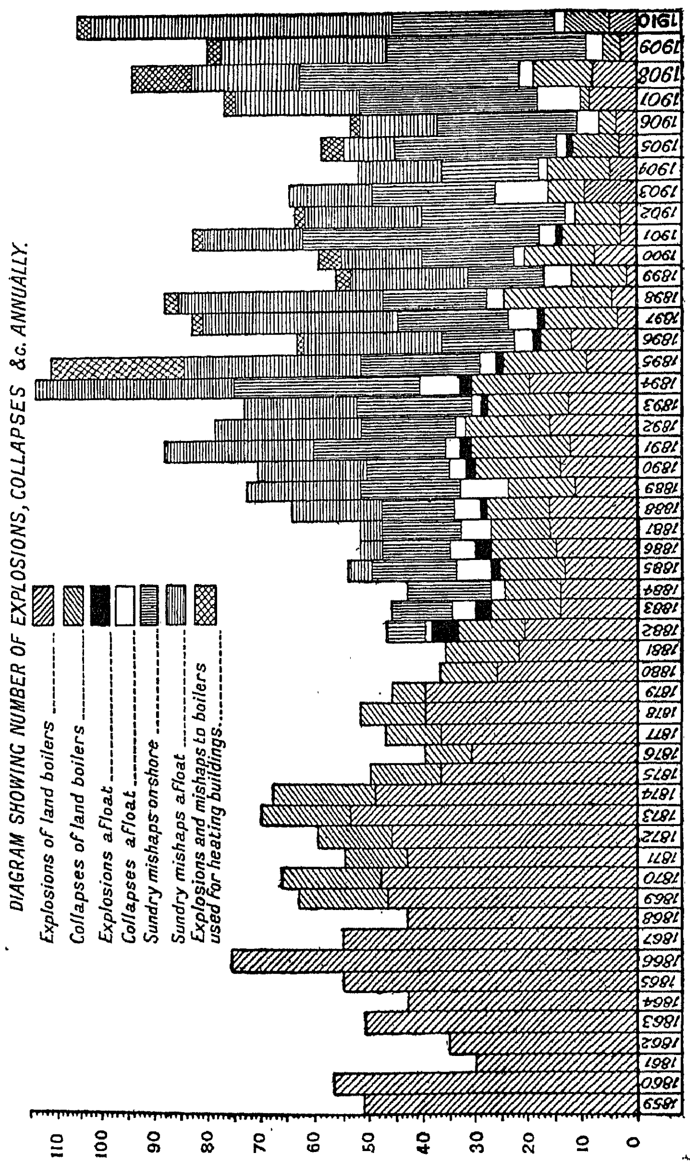
DIAGRAM SHOWING NUMBER OF EXPLOSIONS, COLLAPSES &c. ANNUALLY.
Explosions of land boilers
Collapses of land boilers
Explosions afloat
Collapses afloat
Sundry mishaps on shore
Sundry mishaps afloat
Explosions and mishaps to boilers used for heating buildings.
110
100
90
80
70
60
50
40
30
20
10
0
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
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1899
1900
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1905
1906
1907
1908
1909
1910

designed to withstand that pressure. The pressure of steam is resisted by the strength of the metal of which the boiler is constructed. If the pressure becomes greater than the strength of the metal, the metal must give way and an explosion or collapse occur.

The limit of pressure of steam in the boiler under normal conditions of working is termed the *working steam pressure* of the boiler, and given such pressure the engineer is enabled by mathematical calculation to find the resulting stress per square inch on every plate or joint of the boiler. This can leave no room for dispute.

Also, by reason of very exhaustive investigation and laboratory tests, the stress which different metals are able to withstand before rupture has been determined and is no longer controversial. These results are called the *breaking strength per square inch* of metals (see Table at p. 98).

A margin of safety must be provided to allow for defects in the metal or in workmanship and possible abnormal working conditions. *The breaking strength per square inch* must therefore be divided by some figure to obtain the *safe strength per square inch* of the metal. This figure is termed *the factor of safety.* Given the stress per square inch produced in a plate or joint by the working steam pressure, and the safe strength per square inch of the metal, it is only a question of division to obtain the area of metal required at any section of the boiler. *The factor of safety* is, however, a discretionary figure which varies according to the material of which the parts of the boiler are constructed, the manner of construction and the conditions of working.

A boiler may explode under normal conditions of working and without flaw or deterioration by reason of an error in judgment in design, by fixing the factor of safety too low,

or by reason of an error of judgment in working the boiler at too high a working pressure. In both cases the cause of failure is attributable to the fact that the necessary margin of safety is not allowed.

The Board of Trade, in their regulations as to the survey of the machinery of steamships (hereinafter called "B. T. Rules"), has prescribed certain rules for the determination of the working pressure of a given boiler and the factor of safety to be allowed.

Values of the Factor of Safety.

B. T. Rule 87 prescribes the factor of safety for cylindrical boilers under different conditions. It varies from 4·5 to 6·65, and under certain conditions of construction the surveyor may increase the factor of safety if in his judgment it is necessary [see Appendix C., p. 106].

Cast iron is a less homogeneous material than wrought iron and steel, and is therefore less reliable. The use of cast iron to resist steam pressure in pipes or connections is very much discouraged by the Board of Trade (B. T. Rule 121). If it is used the factor of safety should be relatively high.

Should the factor of safety of any boiler be much lower than those quoted above, it may well be deemed a dangerous one, and if explosion occurs the blame must be upon the head of the person responsible for the use of that factor in the calculation of design or working pressure.

There are many cases reported and investigated where the boiler has been worked at too high a working pressure by an ignorant owner or on the erroneous representation of the maker. An example of a case of this kind is that reported in report 1825, in which case the owner, without knowledge of the strength of the boiler, increased the boiler working pressure from 45 to 60 lbs., thereby reducing the factor of safety. Report 1265 deals with a case where an owner bought his boiler second-hand and without ascer-

taining the safe working pressure, and worked the boiler at a pressure greatly in excess of the safe pressure.

The cause of explosion in all these cases can leave little or no room for dispute, as the matter can be verified by exact calculations and well-known engineering standards of safety margin.

The cases which require closer consideration and allow of greater controversy are those in which the alleged cause of explosion of the boiler is deterioration by corrosion, over-heating or wear; the lack or failure of its safety appliances; its faulty construction, material, or conditions of working.

The causes of explosion for the purposes of this work are divided as follows:—

A. Abnormal Steam Pressure.
B. Weakness.
C. Corrosion.
 (i.) Internal Corrosion.
 (ii.) External Corrosion.
D. Overheating.
 (i.) Shortness of Water.
 (ii.) Deposit on the Plates or Tubes.
 (iii.) Grease on the Plates or Tubes.
E. Waterhammer and Other Causes of Explosion in Steam Pipes.
F. Bad Joints and Miscellaneous Causes.

N.B.—Figures in brackets refer to the number of the Board of Trade Report.

A. Abnormal Steam Pressure.

It has been explained in the foregoing "note" that explosions may occur by reason of an error of judgment or design in providing too small a margin of safety in determining the working pressure in the boiler or area of resist-

ing material; but other cases of explosion due to excessive pressure are those in which the design and normal working pressure are safe, but, owing to some unexpected cause, the pressure in the boiler rises above the normal working pressure.

These cases may be divided under two heads:—

(1) Cases in which the boiler has not been intended to withstand any great pressure and no proper safety appliance has been provided, but which has become subjected to excessive pressure owing to various causes.

(2) Cases in which safety appliances have been provided, but which have failed to act owing to various causes.

1. Cases in which no proper Safety Appliances have been provided.—These cases are fast becoming rare, owing mainly to the working of the Act of 1882, which has brought to light the danger of working any steam-containing vessel without a safety-valve, and to the passing of the Factory and Workshop Act, 1901, which requires all boilers in factories and workshops used for the purpose of generating steam to be fitted with a safety-valve, water-gauge and pressure-gauge. (See p. 6.)

There are, however, outside the definition of the boiler of the Factory Act, many vessels which contain steam and which come under the definition of the Boiler Explosions Act, and sometimes these vessels are not fitted with proper safety appliances.

The most usual example of such case is a hot water heating apparatus consisting of a boiler and circulating pipes. The heating of the water in the boiler causes the water to circulate, and if the circulation is free the total heat of the fire is used in heating and re-heating the water so that no steam is generated. Explosions of heating apparatus, however, are constantly occurring, and are generally due

to a stoppage of the circulation in the pipes which causes steam to generate in the boiler, and, being without safety-valve, the pressure accumulates until it becomes so great as to cause explosion.

The most usual stoppage to circulation in such a case is ice in the winter, many cases of which occur every year, and to prevent this fires ought to be kept going all night in frosty weather. Imperfect circulation, there being insufficient water in the tubes (865) and the failure to open the flow or return valve before lighting the fire (1819) have also caused explosion. In report 1564 the Commissioners made the following recommendations for the protection of hot water heating apparatus in frosty weather:

(*a*) A proper and efficient safety-valve.
(*b*) During frosty weather—the fire to be kept alight *or* the pipes and boiler to be emptied of water when the boiler is not in use, and that the pipes and boiler have necessary fittings for such purpose.
(*c*) The pipes to be protected as much as possible from frost.
(*d*) Printed instructions to be hung up near the boiler for the guidance of those using it.

A very important report of failure of heating apparatus investigated by the Commissioners is 1862(a). In that case the heating apparatus of a school exploded under such circumstances that it was clear that there must have been very excessive pressure in the pipes, but the Commissioners did not express any opinion as to how the pressure was caused. They pointed out the desirability of having safety mountings fitted, but admitted the difficulty of designing a safety-valve which would not do great damage by discharging the water in the pipe, so as to cause a vacuum and waterhammer. They suggested that a hot water pressure-gauge should be fitted.

Another type of "boiler" which is often without safety appliance is a vessel which receives steam from a boiler for the purpose of manufacture or cooking, and which is provided with a relief pipe to exhaust the steam. Such a vessel may not be intended to receive steam at boiler pressure, and may have a reducing-valve fitted between it and the boiler. The valve reduces the pressure of steam from boiler pressure to some pressure which the vessel is designed to withstand. *Neither relief pipes nor reducing-valves, however, are entirely reliable.*

Examples of such vessels are kettles, steam heaters, drying tables, steam mangles, kiers for bleaching, distilling, &c., rag boilers and rubber devulcanisers.

Relief Pipes.—Many cases have been investigated in which the area of the relief pipe has been inadequate to relieve the vessel of the full pressure of steam as it comes from the boiler, so that the pressure has become accumulated and caused explosion.

These cases comprise: blow-off tank in which the blow-off valve became jammed and could not be shut (1777); drying table by the negligent or inadvertent closing of the outlet or relief pipe (1102), (1960); vulcanising pan in which the attendant was misled by the pressure-gauge being out of order (1791); kettle in which the area of the relief pipe was too small (1938); drying cylinder where the area of the inlet was double the area of the outlet (1323), and numerous cases of cast-iron kiers.

Relief pipes are also in danger of becoming choked if the vessel contains material capable of choking it.

Relief pipes of stills for distilling creosote oil have become choked with creosote salt (202), for distilling ammonia with deposit (1972), for distilling tobacco water with fibrous material (1217), for distilling oil with pitch

(1031), causing the pressure in the vessel to accumulate to the full boiler pressure.

Reducing-Valves.—If the vessel is intended to withstand some lower pressure than boiler pressure, the pipe between the boiler and vessel may be provided with a reducing-valve, which, by offering resistance to the passage of the steam, causes the steam to enter the vessel at a lower pressure than boiler pressure. If this valve fails to operate, the steam will pass into the vessel at full boiler pressure. Failure of reducing valves has been the cause of many explosions in such vessels (2089).

Explosion has been caused by the removal of the reducing-valves by an ignorant foreman because he was not satisfied with their working (2050), and the reducing-valve has become inoperative by the sticking of the controlling piston which shuts off the steam when the pressure becomes too great. This has been due to corrosion (1876), dirt which has passed into the steam pipes when the boiler primed (969), and a resinous substance which exuded from the indiarubber diaphragm (1789). Reducing-valves want careful periodical examination, and in every case a pressure-gauge ought to be used, so that, on the valve becoming inoperative, the attendant will see the increase of pressure registered (2064).

From the foregoing it will be seen that *vessels not designed to stand boiler pressure and not provided with proper safety appliances are not free from danger.* Either such vessel should be made strong enough to withstand the full working pressure of the boiler, or it should be provided with a proper safety-valve and pressure-gauge. A pressure-gauge alone is not enough to ensure safety as human negligence to observe it has to be guarded against.

In this respect several important reports have been made by the engineer-surveyor to the Board of Trade, and by the Commissioners on the necessity of fitting all such vessels with proper boiler mountings. The following are extracts from the reports:

Report 1102.—The engineer-in-chief made the following recommendations for preventing explosions in drying tables, &c.:—

(1.) To make the apparatus of sufficient strength to withstand the full pressure of the boiler from which the circulating steam is taken; or—

(2.) To fit the apparatus with efficient safety-valve or valves of suitable size having regard to size of inlet pipe, and to load it or them to a pressure not greater than that which the chest is capable of withstanding with safety; or

(3.) To omit any means by which the orifice of the outflow pipe can be intentionally or inadvertently closed. The area of this pipe should also be sufficiently in excess of that of inlet pipe to prevent the possibility of pressure within the chest exceeding that which it is capable of withstanding when the orifice of inlet pipe is full open to the boiler.

Report 1972.—The Commissioners, after investigation of the explosion of an ammonia still which had failed by reason of the choking up of the relief pipe, fined the owner for not working the still under safe conditions, and made the following recommendations:—

"That a still or boiler of this description should be fitted with proper and efficient mountings (*i.e.*, safety-valve) and a suitable pressure-gauge."

Report 1777.—The Commissioners said:—

"We are of opinion that a blow-off or intercepting tank should be so arranged that a pressure cannot be maintained under any possibility."

Report 1244 refers to the explosion of a C.I. kier which was supplied with steam from the boiler through a

reducing-valve. The valve became inoperative, and the Commissioners held the owners to blame, saying:—

"They ought not to have worked the kier unless they knew how to work it properly, and unless it had a safety-valve and pressure-gauge it could not be so worked."

It appears from these reports, therefore, that in the opinion of the Commissioners a careful owner will fit all vessels which can under any circumstances become subject to steam pressure with a safety-valve and pressure-gauge.

2. **Cases in which Safety Appliances have been provided.**—Explosion from excessive pressure in a vessel mounted with a safety-valve can only result from the safety-valve failing to release the pressure after the safe working pressure of steam in the boiler has been attained. There are three main types of safety-valve, viz., the lever, dead-weight and spring-loaded safety-valve.

Lever Safety-Valve.—The valve is held down by a weight suspended from a lever working on a pivot. In order that the valve should open, the steam pressure on the valve must exert a force, the moment of which around the pivot is greater than the moment of the weight suspended on the lever around the same pivot.

Dead-weight Safety-Valve.—The valve in this case is held down by the weight directly above it, and can only lift when the pressure of the steam becomes greater than that of the weight.

Spring-loaded Safety-Valve.—The pressure on the valve in this case is exerted by the resisting strength of a spring.

Another form of valve, *the spring-balance safety-valve,*

used to be commonly fitted to small portable boilers, and is a combination of the spring and lever safety-valves. The weight on the lever in this case is supplied by a spring capable of adjustment. This form of valve has been characterised by the Commissioners as most objectionable, because by screwing down the balance-spring a valve may be easily overloaded.

Overweighting Valves.—Explosion due to excessive pressure may arise from the overweighting of the safety-valve. An additional weight on the lever of a safety-valve may seriously overload it because the weight on the valve is accentuated by leverage. Numerous cases of explosion by overloading these safety-valves are reported. In many cases such safety-valves have been deliberately overloaded or even wedged down by ignorant or reckless attendants for the purpose of preventing the boiler from blowing off steam, or in order to give the engine a greater pressure of steam (1790). This is a most dangerous practice, and one which is now subject to penalties. (See p. 11.)

Another case of overloading lever safety-valves is reported (1298), in which the upper edge of the lever was not notched to prevent the weight slipping towards the end of the lever, which it did by reason of violent vibration and an inclination in that direction. In case 650 a boiler was situated under a brick arch which, gradually subsiding, pressed down upon the lever of the safety-valve, so making it inoperative.

Dead-weight safety-valves, on the other hand, are very unlikely to become overweighted by anything but a deliberate application of a considerable additional weight upon them. The action of the weight on the valve is direct, and therefore to increase the valve pressure to a

dangerous extent, considerable extra weight must be applied.

The adjustment of safety-valves to the particular working pressure at which the boiler may safely work requires great care and accuracy, and at no time ought to be left to an unqualified or subordinate engineer. The Board of Trade requires that the limit of weight on the safety-valve on board a steamship shall be fixed by an engineer-surveyor to the Board of Trade, and any person placing any greater weight on such valve is liable to a fine of £100 (B. T. Rule 123). In report 1173 the Commissioners said that a safety-valve ought not to be fitted by the pressure-gauge alone. A second gauge should be fitted so that one gauge checks the other.

Wrong Adjustment.—In the case of an adjustable spring-loaded safety-valve, it is most desirable that such valve should be encased in a locked box, so that no unauthorised person can alter its adjustment when once made by the surveyor or responsible engineer. Explosions due to the wrong adjustment of the safety-valve (2023) and the deliberate screwing down of the spring-balance of the safety-valve (85) are reported. The spring of a spring-loaded safety-valve ought not to be very rigid, because in such a case a very small compression of the spring will increase the pressure to a dangerous degree. In one case it was pointed out that $\frac{1}{32}$ inch relaxation of a spring reduced the lifting pressure of the valve from 250 to 160 lbs. per square inch (1377).

Spindle set fast by disuse.—Another cause of failure of safety-valves is disuse, resulting in the valve or valve spindle being set fast by corrosion (113) or by choking with hard scale (853), in which case the Commissioners said that a safety-valve with centre spindle projecting beneath the guide is in danger of becoming encrusted with

scale and is not a proper construction. In order to obviate danger of sticking, the safety-valve should be repeatedly tested by lifting the valve from its seating while the boiler is in use, and on commencing to use a boiler after disuse the safety-valve spindle ought to be taken out, cleaned and black-leaded.

Area and Lift of Valve.—The purpose of the action of the safety-valve is clearly to relieve the pressure in the boiler. It is, therefore, important that the area and lift of the valve should be sufficient to allow as much steam to escape as is being generated in the boiler; for if generation of steam overtakes relief, the pressure will accumulate and so cause explosion.

Several cases are reported (590), (1206), in which explosions have been caused by the comparatively small area of the safety-valve.

The rate of generation of steam is roughly proportional to the amount of fire-grate area of the furnace, whilst the rate of escape of steam from the valve will vary according to the pressure in the boiler at the time; so that B. T. Rule 124 prescribes a minimum area of safety-valve per square foot of fire-grate for boilers working at varying pressures and when the fires are burnt under a natural draught. If the fire is burnt under a forced draught the area given in the table must be multiplied by a number representing one-twentieth of the estimated consumption of coal per square foot of grate in pounds per hour, to find the correct area. (See Appendix C, p. 109.)

The lift of the safety-valve must be great enough to allow the free passage of steam from the valve, and is given by B. T. Rule 125 to be one-fourth the diameter of the valve. Similarly the pipe leading from the valve must be not less in diameter than that of the valve itself.

Stoppage of Valve Pipe.—This has been the cause of explosion in many reported cases. The deliberate stopping up of valve pipes for the prevention of escape of hot steam and water upon men cleaning the boilers caused several explosions (1948). This danger of explosion is accentuated by fixing the safety-valve on the pipe leading from the boiler and not directly connected on to the boiler. In Report 1948 the safety-valve was outside the junction-valve, and men cleaning the boiler had plugged the junction-valve, to prevent hot water dropping upon them, so causing the safety-valve to be inoperative. Writing of this explosion (" The Distington Explosion "), Mr. Hiller says:—

> " Safety-valves should have direct and independent connection to the boiler, and not be connected with the main steam pipe or junction-valve, as in this case there is a greater likelihood of blocking up."

If the contents of the boiler are of the nature which clogs, the danger of stoppage is great. Explosion of stills resulting from clogging of safety-valve pipes are reported: with rags, grass and paper (82), and with froth from crude petroleum (955).

Safety-valves should have stops to prevent them from being blown right out from their seatings when acted upon by the steam or by excessive priming of the boiler (1339).

It should be noted that steam economisers may become subjected to steam pressure if the dampers of the flues are not closed when the circulation of water is stopped, and therefore should be fitted with a suitable safety-valve (1377), (1790).

Pressure-gauges ought to be periodically tested by a standard gauge, as they are a very good test of a safety-valve's action and constitute a second line of safety, but may be misleading if not regularly checked (509).

B. Weakness.

A boiler may be weak by reason of the fatigue of the material, by wear and tear, or the use of unsuitable or faulty material in its construction. This weakness may cause explosion at a pressure not exceeding the working pressure, and such explosions are outside that class resulting from excessive pressure because the primary cause of explosion is a fault in the boiler itself and not in the safety appliances.

It is often difficult to determine whether an explosion due to weakness is caused by an incipient fault in the construction or material (*e.g.*, bad workmanship or a latent flaw), or one which has developed during use, and those which develop during use are often due to some fault in design (*e.g.*, insufficiency of stays).

The stresses in the material of a boiler are "live" stresses, constantly varying in intensity by reason of variations in temperature and pressure. Variations in stress may be accentuated by improper use of the boiler or by the faulty construction or repairs of the boiler, and rapid and large variations cause the material stressed to become fatigued and to lose its tenacity and ductility so that eventually it gives way under the working stress.

Weakness due to improper use of the Boiler.—Sudden changes of temperature are highly injurious to a boiler, and cause in it distortion which sets up severe stresses in the seams. Cold water pumped into the hot shell of a boiler or hardfiring a boiler filled with cold water causes uneven contraction and expansion which induces severe stresses in the seams.

In one case an explosion was caused by injury to the shell of the boiler due to unequal stresses set up in it by blowing the boiler down and rapidly getting up steam again

from cold water (1105), while several cases are reported of explosions under normal pressure due to injury done to the boiler by pumping cold water into it (28), (603). These cases want differentiating from one recently investigated by the Commissioners (2068). In this case, the shell of a devulcaniser was jacketed and into this jacket was let steam for devulcanising purposes. After exhausting the steam, cold water for cooling purposes was gradually let in. It was admitted by the Board of Trade engineers that there was nothing objectionable in this operation, because the cool water in entering the jacket was met by the resisting heat of the volume of caustic soda and rubber within the devulcaniser and did not, therefore, immediately cool the plates, though there might be some injury to the outside shell. Cold air impinging on the furnace plates when the doors are open for stoking, and dampers also open, may cause injury (29). The feeding of a boiler which has become overheated by shortness of water (see pp. 66, 67), with comparatively cold water is very dangerous (1753), as in that case the exposed plates will immediately contract and distort the boiler. Banking fires against the bottom tubes and drain of a water-tube boiler, which were cooled by the draught from the furnace doors when the fire was drawn forward in the morning, caused the metal to become hard and brittle, and eventually to give way under normal pressure (1979). To avoid this danger a brick bridge ought to be built at the back of the furnace in front of the tubes.

The result of the stresses set up by rapid changes of temperature may be to fracture the metal of the boiler, or if no fracture actually occurs, the ductility and tenacity of the metal may be seriously reduced, causing explosion when pressure is got up in the boiler.

Rapid variations of temperature, therefore, must be avoided. Fire doors ought to be opened for as short periods

and as rarely as possible, and the dampers should be shut to reduce the draught. The firing of the boiler filled with cold feed ought to be gradual.

If it is necessary to raise steam rapidly from cold water, artificial circulation may be used. This may take the form of a hydrokineter, or it may be a circulating pump drawing water by suction from the bottom of the boiler and introducing it through the feed near the water level. A boiler ought not to be blown down at a higher pressure than about 10 lbs., lest the cooling be rapid when all the steam is blown off. In one case the fracture of a screw stay causing explosion was due to improper management, the practice being to blow the boiler down at a pressure of 100 lbs. every week (48). Mr. Hiller says:—

"The cooling and emptying of a boiler should be done as gradually as possible. The best course to adopt when it is intended to stop a boiler is: close the damper, shut off the junction-valve, and close the fires. Then allow the boilers to stand one, two or three days, as found necessary, until it and the surrounding brickwork are cooled. Then run the water off, and open the boiler and the flues. . . . Of the more rapid methods of cooling boilers probably the least objectionable is the plan of introducing cold water at the same time as the hot is run out. Where there is a large amount of water available for carrying out this plan, the feed is set to work and the boiler is fed at the same time as the hot water is allowed to run away at the blow out, the inflow being adjusted to the same rate as the outflow. . . . In many cases the boilers are blown off under pressure after the junction-valve has been closed and the fires drawn. The blow out tap is opened and the hot water blown out by the steam. This plan is open to many objections. Amongst the most serious of these is the fact that the sudden and rapid change of temperature is liable to seriously strain the boiler seams; also, the scale and deposit being left on the hot plates are generally baked hard and rendered very difficult to remove.

The most objectionable of all methods of emptying and cooling a boiler is to blow it out under pressure, and afterwards to run cold

water in in order to cool the shell still more rapidly. . . . This plan should never be adopted; it is always likely to seriously injure a boiler." *

An exceptional case of weakness due to improper use was that reported (1812) in which wet yarn passing frequently throughout a period of eight years over a drying cylinder had worn the metal so that it had become too weak to resist the normal steam pressure. The chafing of a loose internal feed pipe caused wear and explosion of one of the fire tubes of a marine boiler (2059).

N.B.—Cases of erosion by fire are included under External Corrosion, p. 58.

Weakness due to Faulty Construction.—Insufficiency of stays or a faulty form of seam may cause the flanges and plates of a boiler to fatigue by the constant movement due to variation in pressure and temperature. This wearing action causes the metal to become hard and brittle, and a groove or crack to be worn in the metal at the point where the expansion and contraction is localised. It is called *grooving*.

Curved Lap Joints.—Grooving often takes place at the curved lap joints of boiler plates because the arc of the circle is distorted by such a joint, so that the stresses due to expansion and contraction are localised near to the line of rivets. Grooving of longitudinal lap joints of horizontal and vertical joints of vertical boilers has caused seam rips of boilers (465).

This danger is obviated by the use of butt joints with two covering plates which preserve the arc of the circle right round the periphery of the boiler.

The flanges of the flat end-plates of boilers are particularly subject to grooving. The varying pressure in the

* "Working of Steam Boilers," by Edward G. Hiller, Chief Engineer of the National Boiler and General Insurance Co., Ltd.

boiler sets up a form of panting in the end-plate, causing a circular crack to develop in the knuckle of the flange of either the end-plate or the furnace flue (2028). A large radius of the flange reduces risk.

There have been many examples of this wearing action. In every case the chief cause has been the lack of or insufficiency of stays. Either there have been no stays (1782) or the stays have not been strong enough to prevent panting (2028), or broken stays have not been renewed (1718). The top plate of a vertical boiler is subject to this panting action and ought to be stayed (1763). Stays themselves may become fatigued by the varying stresses due to steam pressure, especially if the conditions of working of the boiler are heavy (1710), or if there is constant vibration of the boiler bed (1718). If one stay fails by fatigue the other stays are more quickly fatigued (1300). Tubes which act as stays may similarly become fatigued and fail, and such tubes ought to give more than frictional support to the ends by being screwed into the plates (1740). Ends of water-tube drums are not generally flat, but are made to the radius of the drum, so do not require stays. They should, however, be carefully examined for signs of grooving (1699). Some Lancashire and Cornish boilers are now made with deeply dished ends and require no other stays than the furnace flues.

Grooving is generally accompanied by corrosion as the varying stress in the plates accelerates corrosion. (See Corrosion, p. 54.)

Other examples of faulty construction of a boiler causing explosion are *latent flaws*. These ought to be discovered by hydraulic tests before the boiler leaves the makers, but as has been pointed out by the Commissioners' report a hydraulic load is applied gradually, whilst a steam pressure is alive and varying, and an initial flaw may only

become dangerous by the action of the steam pressure (1699). It is of course a difficulty to determine how long a flaw has existed in a boiler which has been in use for some length of time, but the cases of explosion due to flaws in the material do provide some indication of the most usual way in which incipient flaws arise.

Flaws in bolts very often arise from unequal and too great tightening up of the nuts. These flaws which may be caused in the bolts of steam chests (1843) or manholes show the necessity of great care in fitting mountings to boilers. Similarly the over-tightening of tube stoppers may cause fracture (1864), and the screwing up of a stop valve too hard has caused fracture of a valve.

A similar cause of fracture is that of using excessively high pressure in closing rivets or the overheating of rivets by rivet boys (1082), which, together with the contraction of the rivet in cooling, causes the head to fracture. Caulking of the seams with an improper caulking tool or the drifting together of the rivet holes in two plates has caused fracture of the plates.

Punching the rivet holes before bending the plates is a bad practice, because the plate, having lost strength by the loss of metal, is likely to become hard and brittle and so resist bending and cause cracks (60). The holes ought to be drilled, and even this ought to be done after bending (265). (See also B. T. Rule 98.)

Cracks are sometimes developed in the knuckle of a dished end of a boiler by the use of an hydraulic rivetter (1699). In that case the indentation made by the rivetter caused the radius of the knuckle to be reduced from 1 to $\frac{1}{2}$ inch, reduced the thickness of the plate, and made the metal brittle. Similarly hammering in the flanges of a dished end in order to make a good fit between it and the longitudinal plates may cause fracture.

Cracks have also been caused by using a too heavy hammer (6 lbs.) in cleaning off scale in a boiler.

Long externally-fired egg-ended boilers have a tendency to develop *seam rip*, and the Commissioners said (1124) that they required the most careful and frequent attention, whilst if they were very long (*e.g.*, 66 feet in report 873) they characterised them as dangerous to the public.

Other cases are reported (384, 397, 603, 819).

In Report 873 the Commissioners said:

> "Long cylindrical externally-fired boilers are liable to incipient fractures which cannot be detected upon examination by competent persons; that such boilers when working are liable to sudden fracture or seam-rip owing either to the development of such incipient undeveloped fractures or the stresses produced by the unequal temperature to which the several parts of these boilers are subjected, and that in the interests of public safety the use of boilers of this type of extreme length should be discontinued."

In report 2049 it was suggested that the submerging of a ship's boiler while under steam developed cracks.

Cast-iron is particularly susceptible to incipient flaws owing to uneven cooling in the moulds, and this makes it altogether an unsuitable material to withstand high steam pressure. Report 1841 deals with the explosion of the C.I. dome of a locomotive, and it is there stated by the engineer-surveyor-in-chief that cast-iron is not suitable for covers of large openings to boilers. Similarly cast-brass is condemned, especially as brass becomes weakened by a moderate heat (170).

Cast-iron kiers, &c., ought never to be subjected to high steam pressure.

Another common fault in construction is *defective welds*. The welding of seams of small boilers or steam receivers is dangerous (1532), (1890). In the latter case it was pointed out by the engineer-surveyor-in-chief that there

was great difficulty in making a good weld in such vessels because it was almost impossible to get the heat to the seam all round and to work the seam properly afterwards.

The defective welding of stays has also caused explosion (1316), as also of tubes of water-tube boilers (1525).

The detection of fractures in the small screwed stays of a locomotive firebox may be difficult. In Report 2047 the Commissioners said:—

"The hammer test cannot be relied upon as far as the firebox small screwed stays are concerned. Until this explosion no one was aware that any of the firebox stays were fractured. As a result of this explosion the practice of drilling small holes axially in the firebox screwed stays has become more general, and in our opinion it is an additional safeguard."

Weakness due to Faulty Repairs.—Injudicious repairs or alterations of a boiler have frequently led to disaster. The *removal of Galloway tubes* weakens the strength of the flues, and several such removals have resulted in the collapse of the tubes. The Commissioners pointed out in report 1510 that although stays had been substituted for tubes and had been intended to compensate for them, the stays (not having circulating water within them) become heated by the furnace gases and therefore are in grave danger of buckling. Other cases of removal of tubes causing failure are (134, 940, 1565, 1825).

The *cutting of manholes* or sight-holes in boilers without fixing a compensating ring (440) has caused explosion, while in one case the ring was improperly constructed in having the flanges of the angle irons cut at the corners, thereby failing to compensate (969).

The practice of *plugging a tube* of a locomotive under repair with an iron plug and continuing to work the locomotive has resulted in several accidents. In report 1135 the Commissioners said that it was dangerous to work a

locomotive under these conditions, and although it may be necessary to meet an emergency to drive an iron plug, at the earliest opportunity a through rod should be inserted and properly secured. If this were impossible a bolted patch covering the hole should be put on the tube plate. If a rod is used it must be strong enough to withstand the pressure. A weak rod failed while being tightened up when the boiler was under steam (1591).

In one case (1998) *chain studding* was used to repair a short crack in a furnace crown, and subsequently, apparently under normal working conditions, one length of studding was blown out and fresh cracks developed. It was pointed out by the engineer-surveyor-in-chief that such a method of repair should only be resorted to as a temporary expedient because it has no value in reinforcing the strength of the defective plate.

The use of a slide valve cover designed for a low pressure engine for a higher pressure cylinder without making calculation of strength and factor of safety caused explosion (2002).

After repairs an hydraulic test ought always to be applied to ascertain that the joints are tight, &c., but it should never be used higher than twice the working pressure of the boiler (1301).

C. Corrosion.

Corrosion, internal and external, is the most prolific cause of explosion of boilers. By far the greatest number of cases of explosion due to corrosion are directly due to the negligence of the owner in not having the boiler examined before use or inspected periodically during use, and do not arise from any obscure cause. There are, however, certain factors in the management of a boiler which accelerate corrosion, and these are dealt with hereunder.

(1.) **Internal Corrosion** (*i.e.*, on the water side).—Neither hot nor cold water alone has any action on wrot iron or steel, and only a superficial action on cast-iron. The presence of an acid is essential to corrosion* (*vide* experiments by Dr. J. Newton Friend, Proceedings of the Iron and Steel Institute, 1908, ii., 5). Oxygen is also a necessary factor in corrosion.

In boilers acid may be contained in the feed water itself or in the air mixed with the feed water.

The two main causes of internal corrosion are therefore (i.) acid in the feed water, and (ii.) air in the feed water.

The total exclusion of either the one or the other effectually checks corrosion.

(i.) *Acid in the Feed Water.*—It is practically impossible to rid feed water entirely of acid. Carbonic acid is contained in the purest water and the chemical action set up liberates more acid, so that the accumulative effect of a small amount of acid may be very great.

Different qualities of feed water, however, contain a greater or less amount of acid, and many explosions have been due to the use of unsuitable water, causing rapid deterioration (2099).

It would be outside the scope of this work to detail the analyses of waters which have proved corrosive, and it is sufficient here to say that common salt and chlorides of magnesia and lime (which are the most common salts found in feed water) are constituents which accelerate corrosion in a boiler, whilst soda or lime diminish corrosive action. (Mr. Stromeyer, "Advice to Boiler Attendants," 1910, p. 114.)

Every steam user is well advised to have the feed water

* Controversy still rages as to the truth of this statement by Dr. Friend, but as all air contains carbon dioxide, and additional acid is liberated when corrosion commences, the question is of greater theoretical than practical interest.

of his boiler analysed from time to time and only to use antidotes for corrosion on the advice of an expert.

It ought not to be forgotten that river water changes in analysis from time to time, especially at times of drought, and that a user is not justified in using feed water from year to year on the strength of analysis made at the commencement of the use.

Some patent scale absorbers have been found to contain corrosive acids and should never be used without advice.

An injudicious use of soda causes priming of the boiler and leakage of the seams.

(ii.) *Air in the Feed Water.*—Oxygen is a necessary factor in corrosion. The presence of air in the boiler therefore accelerates corrosion.

Air let in with the feed water is given out when the water comes in contact with the hot boiler plates. If the circulation of water in the boiler is not good, the bubbles of oxygen given out below the water line may remain in contact with the plate, or if the air is not allowed to escape it may collect between the water and the steam.

The oxygen thus supplied, in combination with any acid in the water or carbonic acid in the air (however weak) starts a process of rusting which yields up more carbonic acid and thus renews the attack upon the plate. This corrosion, which may take the form of pits eaten into the metal in patches below the surface of the water or just above the water line, is called *Pitting*. This will take place most rapidly where the circulation of water is the least active and where the movements of the boiler by excessive straining will loosen the rust and expose more metal to the air.

Mr. Stromeyer says:—

"Certain it is that if there is any pitting going on in a boiler the greater part is sure to be found along the line of firebars.

Another part which is also severely attacked is the under-side of the furnace and combustion chamber, for here the air bubbles cannot rise if they have once been formed." *

The reports contain many cases of explosion due to pitting or local corrosion. It is a common form of corrosion in water tubes, generally near the headers in the area affected by the expanding of the tubes (2075). It has also caused the explosion of economiser tubes, and in report 2080 it was suggested that such tubes should occasionally be taken out and cut up for examination.

If the air in the feed water is entirely expelled before admittance to the boiler, pitting becomes impossible. The use of distilled or condensed feed water which contains little or no air and a feed pump which introduces no air into the boiler greatly reduces this danger of pitting. (Memo. Chief Engineer of Manchester Steam Users, 1910.)

Leaving a boiler idle without completely drying it and keeping it dry, causes rapid corrosion. If a boiler is left idle while empty it ought to have trays of unslaked lime placed inside it to absorb all moisture and be closed air-tight. If it is to be left full, ready for use, burnt lime ought to be added to the water. Leaving an idle boiler full of water is not a good practice. (Mr. Stromeyer, "Advice to Boiler Attendants.")

The following conditions accelerate internal corrosion:—

(*a*) **Galvanic Action.**—This is the action which takes place in every case where two metals of different potential are connected and immersed in an acid. There is disintegration of the electro-negative metal whilst the electro-positive is preserved.

The lack of homogeneity of the metal of a boiler causes galvanic action between the particles of different potential

* "Marine Boiler Management and Construction."

in the metal. An infinite number of galvanic cells are produced. Carbon is electro-positive in relation to iron, so that the iron suffers disintegration. This was one of the suggested causes of very active corrosion in report 2066.

Where different metals are in contact in the boiler the same galvanic action is produced.

Copper and brass are electro-positive to iron, so in contact with iron they tend to destroy the iron.

On the other hand zinc, tin and lead are electro-negative to iron and in contact with iron tend to preserve the iron, but themselves become destroyed.

Cases 495 and 942 are instances in which corrosion has been accelerated by the contact of metals of different potential.

(*b*) **Animal or Vegetable Grease on the Plates.**—Fats are split up into acids and bases when heated to a temperature of a little over 212° F. and the acids thus liberated attack the iron. Mineral oils are, on the other hand, harmless as they contain only hydrogen and carbon. (Stromeyer, "Marine Boiler Management and Construction.")

(*c*) **Indentation or Scratch.**—The internal surface of a boiler ought to be smooth and even, as a scratch or indentation (especially near the water surface) becomes the centre of corrosion and pitting. (Cushman, "Preservation of Iron and Steel.")

(2.) **External Corrosion.**—External corrosion, when it occurs, is often more rapid than internal. The reason for this is that there is a freer air supply and that the acid-laden fumes from the furnace accelerate corrosion. It ought, however, to be entirely obviated by entire dryness.

The greatest danger of external corrosion is *leakage* from the seams (1762), or from patches (1325), (1734). Any

such leakage will cause rapid corrosion because the acid and oxygen are both present in the air. When the air contains sulphuric acid, as it does in all furnaces, the corrosion becomes rapid and may cause very rapid eating away of the plate.

Leakage may also take place at other joints. Bad fitting of the screwed end of a stay tube (1927) or a screwed plug in the botton of a boiler (1731) or a badly executed patch (1734), have caused leakage which has resulted in corrosion and explosion. In report 1316 the absence of a nut or collar on the stay inside the front end-plate was spoken of as a serious defect in design, as the joint without such provision could not remain steam-tight.

Corrosion from a leakage may be hidden by scale and so evade detection unless a very thorough examination is made (1312).

Damp brickwork is also a grave danger. The metal under the brickwork hidden from inspection may be gradually corroded without knowledge of the owner on this account. It is therefore most important that brickwork should be kept dry and that the brickwork in contact with the metal should be fire-clay brick. Explosion has occurred by the use of common brick in contact with the boiler plate through which the water percolated, giving rise to corrosion (1351).

All parts of a boiler which are in danger of leakage ought to be away from the brickwork and the furnace gases. It is impossible to entirely accomplish this because some parts of the seams must be contiguous to brickwork, but all longitudinal joints should be kept away from the brickwork and the blow-off pipe should be recessed in a manhole so that the joints are not touching the brickwork.

The outside covering of a boiler may be subject to droppings of water which, if laden with sulphur from fumes, will

rapidly corrode the metal if it reaches it (66). The failure to remove the lagging of a traction engine in order to make proper examination resulted in explosion (2067).

The great safeguard against explosion from excessive external corrosion is *thorough inspection.* This can only be relied upon if the boiler is completely stripped for examination and the brickwork in contact with the metal removed periodically. The advice of the chief engineer of the National Boiler and General Insurance Company (Mr. E. G. Hiller), in this respect is important (see Appendix D., p. 118). He advises that the brickwork and non-porous composition of top coverings of unhoused boilers should be removed every five years for examination, and if the boiler is housed, every ten years; and that the porous composition should be removed every ten and fifteen years in the cases of unhoused and housed boilers respectively.

With regard to the flue brickwork he advises that it should be pushed back at each transverse seam every ten years for a length of about 12 inches, whilst vertical boilers should be stripped of their non-porous covering every five to eight years, and of porous covering every seven to ten years. The front cross-seating wall of a boiler should in his opinion be removed every ten years in all cases, and every two or three years if it is more than 9 inches wide, whilst if the seating is damp it ought to be removed every year.

A common cause of external corrosion is damping the fires with moisture-laden ashes. Their moisture, laden with sulphur from the fuel, attacks the metal very rapidly. Similarly, to allow damp ashes to rest against the blow-off pipe or boiler front is dangerous (1996).

Corrosion and Erosion of Fire Tubes.—Many cases are reported in which the tubes of a boiler have become very

rapidly worn thin by corrosion and erosion caused by the use of coke containing sulphur and the forcing of the draught by the blower. The sulphur-laden fumes have caused corrosion whilst ashes and cinders have been carried by the draught through the tubes at high velocity, scouring them and wearing them away.

In tramway and locomotive boilers this has caused many explosions. Brass tubes have been known to wear and explode in this way in about two years when worked under heavy conditions (1778), (1849), whilst copper tubes have worn away in the same manner in rather longer periods (1815). Tubes when inspected should be probed to detect pitting or wasting (1336).

To obviate this danger it is most desirable that the tubes should be drawn regularly to ascertain their actual condition, and they should be periodically subjected to an hydraulic test (1849).

D. Overheating.

The metal plates and tubes of a boiler adjacent to the fire and in contact with the furnace gases would become heated to the temperature of the gases if it were not for the presence of water in the boiler on the other side of the metal. The temperature of the water in the boiler depends upon the pressure at which steam is raised (see Table, p. 104), but rarely reaches a temperature greater than 400° F. (pressure 250 lbs. per square inch), so that while this is in contact with the metal on one side the plates cannot greatly exceed this temperature though there be gases at a temperature of over 2500° F. on the other side. The heat on the furnace side is conducted through the metal to the water and there is used in forming steam, so that it is prevented from heating the plate to the temperature of the

gases. If, however, there is any obstruction to the transmission of the heat from the furnace to the water, the metal of the plates will retain the heat and rise in temperature and become red hot. Metal loses strength when heated, and if it becomes red hot has comparatively very little strength to resist the pressure of the steam within the boiler. The result is, therefore, that when these plates are heated beyond a certain temperature their strength is so seriously reduced that the internal pressure of the boiler overcomes it and the plate is bulged out and fractured.

The following table given in report 253 is the result of experiments made at the Franklin Institute on iron boiler plates at high temperature, the mean maximum tenacity being at 550°=65,000 lbs. per square inch.

Temperature F°.	Percentage Diminution of Tenacity.	Temperature F°	Percentage Diminution of Tenacity.
550	0	932	33·24
596	8·99	1030	44·78
652	11·55	1111	55·14
722	14·36	1155	60·00
766	15·89	1237	66·22
824	20·10	1317	70·01

Metal is a good conductor of heat. The heat of the gases is conveyed away from the plate to the body of water inside the boiler by rapid circulation, but if (i.) steam is in contact with the plate because the water level is too low, or (ii.) there is a deposit of material with low conductivity (*e.g.*, lime, mud, dirt, &c.), or (iii.) there is grease on the plate—then in any of these cases the heat is not conducted as readily from the metal to the water and the temperature of the plate rises in consequence. These causes of explo-

sion or collapse must be considered in detail and the contributing causes of each.

1. **Shortness of Water in the Boiler.**—Steam is, compared with water, a bad conductor, so that if the level of water in the boiler becomes lower than the highest part of the metal plates or tubes in contact with the hot furnace gases, the heat is not as rapidly carried away from the plate or tube, which therefore becomes red-hot.

As will be seen from the table on p. 29, a great number of explosions and collapses have been attributed to this cause.

The mountings of the boiler which mitigate the danger of allowing the level of the water to fall below the height required are:

(i.) Water-gauge glass.
(ii.) Low-water alarm.
(iii.) Automatic feed regulator.

The first is a tube of glass connected at the top and bottom to the boiler, in which glass the water will rise and fall with the rise and fall of the water in the boiler. The level of the water in the glass indicates to the boiler attendant the level in the boiler, and when all the water goes out of the glass the level of the water has become dangerously low. It is very important that the glass should indicate correctly, as from those indications the attendant uses his judgment in supplying the boiler with feed water.

Another safety appliance is the low-water alarm. This alarm is actuated by a float which, resting on the water and sinking with it, causes a valve to open when the water falls to a dangerous level. The escaping steam sounds a whistle which gives the alarm to the boiler attendant. (It may also be mentioned here that many low-water alarms

are also fitted to give alarm when the water in the boiler reaches its highest safe level. Filling the boiler too full causes the boiler to prime and water to be carried in the steam pipe, thus increasing the danger of waterhammer or water in the cylinder.)

Neither the water-glass nor low-water detector is "fool-proof," as in the one case the attendant may neglect to notice the gauge, and in the other case disregard the alarm whistle.

Many users do not fit their boilers with low-water detectors. It is contended that an attendant in charge of a boiler fitted with this mounting is more likely to disregard the water-gauge, and therefore the boiler is wholly dependent upon the working of the low-water alarm. Accidents have occurred by failure of low-water detectors. In one case there was an error in judgment in fixing the relative weights of the float and balance when the float was immersed in water (397), and in another case the alarm failed to act, whilst in another the whistle was deliberately gagged. In report 509 the Commissioners said: "A stone float is not always reliable and a water-gauge ought to be fitted as well." And the same opinion was expressed in report 1504.

An automatic feed regulator is a fool-proof safety appliance, but one which is itself in jeopardy of breakdown, and therefore should not be used to the exclusion of the water-gauge and low-water detector.

An appliance which, though not proof against over-heating of the plates lessens the danger of serious explosion therefrom, is the *fusible plug*. These are metal cones fitted into the furnace crown of a firebox and into the plates immediately above the fire, held in position by an alloy of low melting point. If the furnace plates become over-heated the alloy melts and the cone drops, allowing

the steam and water to escape into the furnace and put out the fire.

Fusible plugs will not act unless kept clean. Numerous cases of over-heating have been investigated in which the boiler was fitted with a fusible plug which failed to act owing to the plate over the plug having upon it a deposit of scale (41), (2004), or through the plug having become choked with scale so that though the alloy melted, the scale prevented the water and steam from escaping into the furnace (55), (2096). It is advisable that the fusible plug should be taken out occasionally and re-set with alloy in order that the scale upon it can be got rid of. Insurance companies recommend that this should be done about every eighteen months or two years.

It requires considerable pressure to blow out the plug, and therefore if overheating takes place before steam pressure is obtained the water will not escape from the boiler (1753).

A fusible plug of large diameter is extremely dangerous as the rush of steam into the furnace would then become so great as to cause damage to the attendants in the boiler house. Report 1965 deals with a case in which a fusible plug of one-inch orifice melted and the consequent rush of steam caused considerable damage. The Commissioners recommended that the area of fusible plugs should be reduced to the smallest practical limits.

Shortness of water in the boiler may occur by reason of the direct negligence of the attendant in failing to feed the boiler with water (1504), or:

1. *Failure of the feeding pump* and the lack of auxiliary means of supplying the boiler with water. One common cause of failure of the feeding pump or injector is choking from dirt, mud, or deposit. The feed pump requires the same periodical cleaning as the boiler.

2. *Failure to feed* through being misled by indications of water-gauge by:

(*a*) *Indistinct level of water in the gauge*, by bad light in boiler house or by the gauge not having reflectors for the purpose of making clear the level of the water (1765).

(*b*) *Improper adjustment of the water-gauge* by not allowing for the list of the vessel in the fixing of the level of water required (1776), or working boiler without renewing a broken water-glass (1686).

(*c*) *Total or partial stoppage of the by-passes of the water-gauge*, which either prevents the water in the glass from falling as the water in the boiler falls or prevents the steam pressure entering through the top by-pass. Stoppage may occur: by scum, the boiler not being provided with scum cock (1725), by the rubber rings to the water-glass being forced up into the opening of the glass owing to the glass tube being too short or being fitted loosely into the bottom box (1739), or by the deposit from impure feed water (1601).

On account of the danger of stoppage it is most important that the steam and water by-passes of a water-gauge should be frequently tested by blowing water and steam from both the bottom and top cocks alternately through the drain cock (2106). The glasses of the water-gauges may themselves burst, and it is advisable to protect the glass by wire-netting if high pressure is used (Factory and Workshop Act, regulation, p. 9), especially boilers subject to vibration, or in danger of encountering cold draughts or being splashed upon by cold water. A double set of water-gauges is strongly recommended (2004).

3. *Leakage.*

(*a*) *Through Blow-off Cock.*—For the purpose of clearing the bottom of the boiler of scale or mud deposit, the blow-off cock is frequently momentarily opened while the boiler is under steam. If something prevents the blow-off cock from shutting (1777) or, if by inadvertence, this cock is not entirely shut afterwards (360), the water in the boiler will escape and cause shortage of water. In order to guard against the negligent leaving open of this cock the key of the valve ought to be designed so that it is impossible to withdraw it unless the cock is closed (B. T. Rule 138).

The blow-off cock pipe can be tested for leakage by feeling whether the pipe is hot outside the cock.

(*b*) *Through the Check-Valve.*—This is a valve connected with the feed arrangements and which is provided to prevent a back rush of steam and water when the pressure of the feed pump or injector is released. If by some obstruction the check-valve fails to shut, the water will be blown through this valve. It is, therefore, better that the open end of the internal feed pipe should be fixed at a level above the furnace crowns so that even if leakage takes place the level will not be reduced below that of the furnaces (613, 782).

(*c*) *Through defective Seams and Joints.*—If the water is left in the boiler all night, or over the week end, though the level may have been satisfactory when left, it is most important to test the water level (by test cock and water-gauge) before lighting the fires. Through the attendant omitting to test the level, believing the water-glass to show a full tube when it was empty, overheating occurred in a boiler

which had leaked overnight (1753). Shortness of water has also been caused by leakage past a stopper which was imperfectly fitted into a smoke tube which had failed (2087).

Shortness of water may occur in water-tube boilers by reason of a partial or complete stoppage of circulation in any or all of the tubes. The water in the tube or tubes will in such a case become rapidly formed into steam, forcing out the water and causing the tube to overheat (676), (1168). A similar failure occurred in a heating apparatus on account of water being blown out of the boiler through the return valve owing to the absence of a non-return valve (2039).

In vertical boilers the uptake is in contact with furnace gases on one side and steam on the other. This will cause overheating of the uptake if not protected. Usually the form of protection is a fireclay or cast-iron lining.

With regard to the *steps to be taken when it is discovered that the water is low*, Mr. Hiller says:—

"It is difficult to give any advice which is applicable to the treatment of a boiler in which the attendant finds out that the water is too low. The time which elapses between the furnace crown becoming bare and the actual consequent collapse may be short or long, according to the circumstances of the case. In some instances there may be time to carry out certain precautions, with a view to averting a serious accident, while, on the other hand, the time may be so short as to render any attempt to carry out those precautions a most dangerous and inadvisable proceeding. Generally, if it is found that the boiler is short of water, the dampers ought to be at once closed, the safety-valve eased, and, if possible, some damp ashes or other incombustible material (which would smother the fire) thrown on the fire. This step is usually better than drawing the fires, as the latter might cause a sudden rise of temperature in the furnaces, which would tend to increase the overheating of the plates. If on opening the fire doors it is seen that the furnace crowns are already heated, no

attempt to withdraw the fire should be made. The other steps before mentioned should, if possible, be taken, the feed also being turned on. Attempts to draw the fires when the furnace crowns are heated have often resulted in the attendant being killed.

"If the attendant finds, on opening the fire door, that the furnace crowns are red hot, the best course is to withdraw from the front of the boiler at once, and to warn everyone in the neighbourhood, as it is probable that an explosion or most serious accident is about to occur.

"If the boiler is one of a range, the junction-valve should be shut off, otherwise the steam from the other boilers may enter this one, causing increased damage to this boiler and possibly dangerous priming in the others." *

2. **Deposit on the Plates or Tubes.**—The deposit of a material of low conductivity on the plates or tubes of the boiler retards the transmission of heat from the furnace to the water, holding the heat and causing overheating by which the plate or tube loses strength. (Table, p. 60.)

Feed water containing lime or magnesium carbonates deposits these materials on the plates or tubes of the boiler by reason of the carbonic acid being driven off by boiling.

These deposits, precipitated under pressure, form a hard scale on the plates and tubes of the boiler which may become a source of very great danger. A deposit of scale $\frac{1}{8}$ inch thick on tubes and $\frac{3}{8}$ inch thick on plates has been sufficient to cause a tube or plate to overheat to such an extent as to considerably weaken it, and result in collapse or explosion (2015).

Similarly deposits from muddy feed water on the boiler plates is dangerous (1524) (*e.g.*, canal water).

Water-tube boilers are particularly susceptible to overheating by scale and deposit. The tubes require special attention in the matter of thorough cleaning (1842). There is a danger of any sediment being deposited at the bends

* "The Working of Steam Boilers," by Edward G. Hiller, Chief Engineer of the National Boiler and General Insurance Co., Ltd.

of the bottom of the tubes, and the Commissioners pointed this out, remarking that all water-tube boilers require constant attention (1720).

Many means are provided for reducing the amount of hardness in the feed water. The most important is by the use of water softeners. In a paper entitled, "An inquiry into the workings of various water softeners," delivered before the Institution of Mechanical Engineers in 1903, Messrs. C. E. Stromeyer (the Chief Engineer of the Manchester Steam Users' Association) and W. B. Baron give principles and effects of all the most important means of softening water.

It is not, however, safe to entirely rely on either chemical or mechanical softeners, and this does not dispense with the necessity of frequent and periodic examinations of the boilers. In a recent case (1720) the softener was not kept at a proper temperature so that sediment was carried into the boiler, which was but annually cleaned. The Commissioners said:—

"We desire to say that in our judgment it is a great mistake to place too much reliance upon water softeners. After all, the best way to see whether a boiler is in order is to open it up and inspect it, and we should observe that frequent cleanings and examinations of the tubes of this type of boiler (water-tube) are most important."

In case 1994 too much reliance was put on water softening plant and the boiler had not been cleaned for over six months.

In regard to the form such examinations should take, in report 1301 the Commissioners said, speaking of the advisability of periodic hydraulic tests for water-tube boilers:—

"We regard this test when properly and judiciously applied as a useful adjunct to examination, but we feel that to subject all boilers of this type to periodic hydraulic tests as a means of

examination might lead to the adoption of such test to the exclusion of other means which should, in our opinion, be taken to ensure the safe working condition of these boilers.

"The means we recommend are as follows :—

"The use of suitable feed water.

"Frequent examination of the tubes until proper periods of thorough cleaning have been ascertained.

"The cleaning of all tubes at those periods, and their examination after such cleaning by a competent person.

"Abstention from forcing the fires so that the natural circulation of the water in the boilers may not be interfered with.

"Withdrawal of some of the tubes and cutting them for examination from time to time.

"The substitution, as opportunity offers, of solid drawn steel tubes for lap welded iron tubes.

"With regard to the intervals at which the tubes should be cleaned out, we desire to call attention to the fact that water in a boiler when standing or under banked fires is liable to deposit the same or even a larger amount of solid matter than is a boiler at work under steam pressure."

The length of period between examinations and cleaning is not stated because such period must depend upon various causes.

It will depend principally upon the quality of feed water. If the water is very hard the cleanings must be frequent, whilst if it is free from deposit the periods may be longer. However, whatever the nature of the feed, examinations ought to be made frequently, and in respect of water-tube boilers with softened feed the Commissioners have on more than one occasion approved that the period between cleaning should not exceed 500 working hours, and between examination, of at least the bottom tubes, should not exceed six weeks (1684), (1720).

In regard to all boilers, fire-tube and water-tube, the Coal and Metalliferous Mines Regulations call for cleanings "at least every three months, and oftener if necessary."

A blow-off pipe of an externally-heated boiler passing

through the combustion chamber is particularly susceptible to overheating with very little deposit in the pipe (1218).

If feed water contains salt in solution the solids will not be deposited until it becomes saturated. Before saturation point is reached a solution of soluble salts becomes too dense to ensure safe working. The dense liquid does not circulate properly, and becomes so dense near the plates as to cause crystals to be deposited and heat transmission checked.

The constant use of the *salinometer* (which indicates the density of the liquid) is essential to the safe working of a boiler fed by salt water, and such density must never exceed 4/32, though salt water does not commence to crystallise until it reaches 8·4/32 (Stromeyer, "Marine Boiler Management and Construction").

Condensers have been installed upon most steamships now, but if by reason of their failure salt water is used it must be tested frequently with the salinometer and the boiler blown down when the density reaches the limit indicated above.

3. **Grease on the Plates or Tubes.**—Grease on the plates or tubes of boilers is extremely likely to cause overheating. It offers ten times the resistance to the transmission of heat as does scale. Stromeyer also points out that even a film of grease $\frac{1}{1000}$ of an inch thick may cause overheating, and suggests that tough bubbles are formed by it on the plates containing superheated steam which obstructs the transmission of the heat. Cases of grease deposit causing explosions are 757, 1332 and 1994.

If, therefore, there is oil in the feed water (*e.g.*, by the mixture of exhaust steam) it must be most thoroughly filtered before it goes into the boiler. The grease is contained in very small particles, and unless they are collected

together by chemical or electric treatment they pass through the filters. The better way of avoiding grease in the boiler is to keep the exhaust steam separate from the feed water.

In his annual report for 1896, Mr. Michael Longridge (Chief Engineer, The Engine, Boiler and Electrical Insurance Co.) makes the following recommendations to prevent overheating through grease deposit.

"*Non-condensing Engines.*—Prevent the steam from non-condensing engine, when used for heating the feed water, mixing with the latter unless the quantity of oil used in the cylinder be small, the water pure and the boiler pressure low. Even then it is safer to pass the steam and water through tubes or to keep the two separate in some other manner.

"*Surface-condensing Engines.*—Reduce the quantity of oil used in the cylinder of surface condensing engines as much as possible, and pass the water from the hotwell through sawdust or some other grease-absorbing medium before allowing it to return to the boiler. If there be much carbonate of lime or magnesia in the feed water, then either the water used for filling the boilers and making up the waste should be purified or distilled, or the discharge from the hotwell should be run to waste and every particle of grease excluded from the boiler. In such cases the water surface should be scummed frequently during the day, and the boiler should be laid off for cleaning at short intervals. When the pressure is high these precautions are doubly necessary; *indeed it may be doubted whether such waters should be used at all without previous purification or filtration.*"

It is clear that in water-tube boilers, where cleaning is so difficult, such water should always be purified before use.

Overheating may also be contributed to or caused by hardfiring.—In the case of a water-tube boiler hardfiring may drive out the water in a lower tube where circulation is retarded by clogging with deposit. In case 1340 the engineer-in-chief said that:

"The consumption of coal per square foot of grate (30 lbs. per

hour) was, in my opinion, altogether excessive for a perfectly clean boiler, and fully accounts for the trouble experienced with tubes. It should also be remembered, in dealing with boilers of this type, that an amount of deposit, local or otherwise, in the tubes which would be comparatively harmless at ordinary rates of evaporation, becomes a grave source of danger when the boilers are unduly forced, as they appear to have been in this case ; and such high rates of coal consumption should, I think, be discontinued if the boilers are to be worked in safety."

In a later case (1475) a vertical boiler was fired by the waste gases from a steel slab heating furnace, and the inspector found no evidence of shortness of water, and therefore considered that the explosion was brought about by the excessive heat in the furnace at the time, which caused *priming* and thus led to the plate being overheated.

An earlier and similar case is reported (229), and overheating caused by the injudicious use of the blower in a locomotive (548) also resulted in explosion.

Oven tubes are in danger of becoming overheated by hardfiring. The concentration of the draught in one place (1705), or the non-repair of the brickwork so that a longer length of tube is exposed to the fire than intended (1706), (2040), may be immediate causes of overheating. By repeated overheating the metal of such tubes may become fatigued (1866). Welded tubes for such a purpose have been condemned as they become subject to very high pressure, and welds may prove defective (1585, 2073).

Constant repair of brickwork and a well distributed fire seem to be the chief requirements for the safe working of similar ovens.

Effects of repeated overheating.—Where a boiler is overheated in any of the above ways, but without disaster, it ought to be tested by hydraulic pressure before use. Overheating not only makes the plates brittle (1524), but it produces or aggravates flaws in

the material of the boiler. Though the overheating be only very slight it reduces the tenacity of the metal (1276), and in many other cases there have been strong indications of a continued series of overheatings, none of which were in themselves sufficient to cause disaster, but the accumulating effects of which eventually destroyed the tenacity and strength of the boiler.

E. Waterhammer and Other Causes of Explosion in Steam Pipes.

Explosions of steam pipes are explosions of boilers defined by the Boiler Explosions Act, 1882 (*Reg.* v. *Commissioners of Boiler Explosions, ante*, p. 2).

Such mishaps are very frequent and have been the subject of several formal investigations.

The chief cause of explosions in steam pipes is *waterhammer*, but other causes which lead to disaster are: defective brazing of copper pipes; no allowance for expansion or vibration, defective expansion joints, and improper supports.

These are treated, with report references, in the following pages:—

1. **Waterhammer.**—That there still remains some mystery about this phenomena is testified to by the Commissioners in the report of the last formal investigation where waterhammer was found to be the cause of explosion (1761). They said:—

> "The causes of and results produced (by waterhammer) are not all known to engineers, and explosions do occur which are undoubtedly due to waterhammer under circumstances which are novel and which are such as would not under ordinary circumstances in the first instance have caused the engineer to come to the conclusion that explosion results therefrom."

Since the publication of the above report Mr. Stromeyer has issued a report to the Steam Users Association, 1910,

dealing exhaustively with all the known causes of waterhammer. In it he has considered every report of the Board of Trade from 1882, and has given illustrations showing how the effect has been produced in each case. In order to thoroughly appreciate the dangers of waterhammer and understand how they may arise, readers are referred to that report. The following notes will, however, explain the chief causes and suggest means for its avoidance.

Waterhammer action is, as the name suggests, the hammer of a body of water against the pipe. This knock may stress the metal beyond its strength and cause it to explode. Whatever other factor is necessary to cause waterhammer there must therefore be water present in the pipe at the time of the explosion. There must also be movement of the water.

The movement of the water is always due to condensation of steam which, creating a partial vacuum, causes the water to surge up and hammer the pipe. Condensation of steam will always take place if a comparatively cold surface of the water is exposed to it.

In the report above referred to Mr. Stromeyer divides the cases of waterhammer reported by the Board of Trade from 1882 to 1909 into ten classes, which, with his permission, are stated below.

Class A. Explosions of pipes due to draining.—This class embraces those explosions of steam pipes which have been caused by accumulation of water in a low-lying steam pipe, which water was then partly drained off, whereby a long surface of relatively cold water was exposed to the steam in the upper portion of the pipe. This water surface would condense large quantities of steam which, rushing through a constructed channel, would raise up waves and thereby isolate the further away portions of steam; this steam would condense and leave a vacuum into which the

raised wave would shoot with great velocity and deliver a waterhammer blow. (Mr. Stromeyer attributes six cases to this cause, of which 1787 is the latest case.)

Class B. Explosions of pipe-ends due to draining the pipes.—In this class the cause of explosion is similar to that given in Class A, except that, as the pipe was strong enough to resist the waterhammer blow where it occurred, the pressure wave travelled along in the water in the pipe and produced a fracture where it was doubled by reflection at the end of the pipe. (Mr. Stromeyer attributes forty-seven cases to this cause, of which 1472, 1619, 1685, 1761, were formally investigated.)

Class C. Explosions due to admission of steam to pipes containing water.—This class embraces all those cases in which waterhammer action was produced by admitting steam into pipes containing water. The water-level is low, and as soon as steam is admitted and condensation takes place the rush of steam sweeps up a wave which is propelled towards the vacuum side. (Mr. Stromeyer attributes eighteen cases to this cause, of which 1109 and 1582 were formally investigated.)

Class D. Explosions due to introducing water or condensing in steam pipes.—This class embraces all those cases in which, as far as judged, the waterhammer conditions were brought about not by introducing steam into a pipe which contained water, but by introducing water into a pipe which contained steam, or by condensing steam. (Mr. Stromeyer attributes four cases to this cause (1283, 1486, 1557, 1653).) Report 2011 appears to refer to a case of this class since Mr. Stromeyer issued his report. In this case the cold water let into the pipes of the economiser containing steam caused waterhammer, which might have been prevented by the use of a non-return valve.

Class E. Explosions due to introducing steam under a

column of water.—(Mr. Stromeyer attributes three cases to this cause (1059, 1334, 1417).)

Class F. Explosions due to steam and water on two sides of a valve.—This class embraces all those cases in which the accident was caused by opening a valve when there was steam pressure on both sides of it and water on at least one side, as may happen when there is steam in the main, and steam is being raised in a boiler which has been out of use. Under such circumstances it is customary to wait till the two gauges show equal pressures, though gauges are never quite reliable, and then the connecting valve is opened deliberately. Sometimes the valve of the boiler in which steam is being raised is merely eased while the under pressure is still low, and it lifts of its own accord when the pressure equals or exceeds the pressure in the steam main. If water is resting on the opening valve a waterhammer results, apparently without cause, which bursts the valve. All these cases are very nearly related to Class E. (Mr. Stromeyer attributes eight cases to this cause, of which 1751 was formally investigated.)

Class G. Explosions due to moving plugs of water. —This class embraces those cases in which plugs of water which seem to have been travelling along pipes were suddenly arrested. In case 1617 the propulsion was clearly due to a vacuum on one side, whereas in some other cases there may have been steam or air in front of the advancing water which would escape easily through a relatively small opening, whereas the water would be checked. The sudden reduction of velocity when the water reached the orifice would result in a high pressure which would cause the pipe or valve to burst. (Mr. Stromeyer attributes eight cases to this cause, of which 1076 and 1617 were formally investigated.)

Class H. Explosions due to damming up water.—This

class embraces those cases in which it has been surmised that the flow of steam in a long and often complicated main has dammed up water in unused portions of the pipe, and that a fluctuation of the velocity of steam brought about changes which created conditions favourable for raising waves and producing a waterhammer. (Mr. Stromeyer attributes six cases to this cause, of which 1646 is the latest case.)

Class I.—Explosions which have not been fully reported; and

Class J.—Explosions which are probably not due to waterhammer, *i.e.*, Mr. Stromeyer differs from the Board of Trade engineer as to the cause of explosion.

The fracture of a pipe due to waterhammer does not necessarily take place near the point at which the water is first set in motion. The water in the pipe set in motion as described may travel long distances in waves or in a plug before causing disaster, and the usual point of fracture is either a dead flange, a junction or a valve.

Prevention of Waterhammer.—The following is a summary of Mr. Stromeyer's deductions from an examination of the Board of Trade reports:

(*a*) *A single boiler.*—If the junction-valve is at the highest point of the steam pipe range without any possibility of water lodging in the pipe from the junction to the engine there will be absolute safety from waterhammer.

(*b*) *Two or more boilers.*—There is more danger, because of the possibility of damming up water in a junction.

(*c*) If the steam pipe rises after leaving the junction-valve; if the steam pipe falls and then continues horizontal or slightly inclined towards the engine or if any portion of the pipe bends upwards; then water can accumulate in the pipe and cause water-

hammer. In order to prevent this all pockets should be provided with water-catches having gauge glasses and automatic drains.

(*d*) Drain cocks are dangerous—if kept partly open they are likely to choke (1915), and if used occasionally may create waterhammer.

Mr. Stromeyer concludes:

"It is certainly wrong to assume, as is generally done, that there is safety either in a horizontal or in slanting pipes."

In report 1673 the engineer-surveyor-in-chief said:—

"The only safe way to clear pipes charged with water is to first shut down the boiler stop valve and drain the water away gradually at first; the boiler valves being only opened to admit sufficient steam to blow out the water slowly and heat up the pipes, after which they may be fully opened without fear."

Automatic steam drains themselves get out of order and require periodic overhauling to see that they are not choked or stopped up in any way (1673), (1935).

The lagging of steam pipes reduces condensation and therefore mitigates danger of waterhammer (1476), and the sudden opening of any steam valve is extremely dangerous (1617), (1830).

With the exception of fourteen out of the twenty-one cases of waterhammer in pipes all the explosions that took place were in cast-iron pipes or valves. Only two cases of waterhammer are reported in steel pipes (1360, 1557). Ten cases are reported of failure to copper pipes (340, 468, 512, 572, 580, 933, 986, 1056, 1515, 1582).

Other causes of explosion of steam pipes and valves are:

(i.) Vibration.
(ii.) Expansion.
(iii.) Lack of Support of Steam Pipes.
(iv.) Bad Steam Pipe Joint.
(v.) Lack of Ductility in Steam Pipes.
(vi.) Defective Brazing of Copper Pipes.

(i.) **Vibration.**—Many cases are reported in which pipes have failed through too great rigidity.

Steam piping of ships is especially liable to fracture on account of vibration of the machinery owing to the racing of the engines in heavy weather (1954), or to the movement of the machinery due to the engine seat working loose (1898), (2088), or due to not being properly secured to the hull (1268).

The hull of a ship is itself strained in bad weather and causes the machinery (boiler, engine, &c.) to move relatively to the pipes. This may cause explosion if the pipes are too rigid (1709). To prevent explosion from vibration the hangers for supporting the pipes may be fitted with springs to give some freedom of movement.

(ii.) **Expansion.**—Provision must be made for the expansion of pipes. This is usually provided for by expansion joints or corrugations and the amount of provision depends upon the length of pipe and range of temperature. An expansion joint may become set fast by deposit if not carefully examined from time to time (1404).

Blow-off pipes held rigidly in the brickwork, or earth and ashes, are unable to accommodate themselves to the movement of a boiler due to expansion and contraction (1615, 1996).

(iii.) **Lack of Support of Steam Pipes.**—This is a frequent cause of fracture of the flanges of a steam pipe and one which can clearly be easily avoided. The pipe between supports acts as a beam with a bending stress which is localised upon the largest diameter, *i.e.*, the flange of the joint (2045).

A pipe must be securely anchored at the expansion joint if this be at a bend, else the expansion of the pipe will move the bend out of place (1855). Also all expansion joints

must have a fixed collar and guard belts, or else the spigot will be blown out (1331), (1702), (2117). The removal of a hanger supporting the steam pipe while under steam caused explosion (1671).

(iv.) **Bad Steam Pipe Joint.**—Undue stresses are set up in the metal of the flange of a pipe by tightening up the bolts if the ring of jointing material is wholly within the bolt circle, and many failures have been reported from this cause (1840), (1943). The overstraining of the metal of bolts in tightening up is a very common cause of failure (1843). [See also p. 84.]

(v.) **Lack of Ductility in Steam Pipes.**—It is clearly most important that steam pipes, subject as they are to a "live load" and vibration and possible shock from waterhammer, should be constructed of a material which is both ductile and tenacious.

Cast-iron has often been characterised as very unsuitable for steam piping or valves. The B. T. Rule 121 requires that if surveyors find that cast-iron is employed in such a manner as to be subjected to the pressure of steam or water they should report the circumstances to the Board of Trade. Cast-iron is a comparatively brittle material, and by continuous vibration it may become by fatigue so brittle as to be unable to withstand any variation in stresses (1635).

Cast-iron is also very liable to incipient flaw (1973). In the moulding of the pipe or valve there is danger of unevenness in thickness around the pipe (1798), (2005).

Hydraulic pressure may not detect such flaws or brittleness because it is applied gradually, and in that case the danger is only appreciated when damage is done under steam. Drilling the pipes and hammering to obtain a "ring" are no doubt suitable tests to make on a casting

subject to steam pressure in order to detect unevenness in thickness and flaws or brittleness respectively.

Mild steel is more ductile than cast-iron and not so liable to flaws or fatigue, and this metal or copper ought to be rapidly substituted for cast-iron.

Copper pipes are ductile if kept from damage by overheating. Copper will, however, deteriorate by a comparatively low heat. It was stated that copper loses 25 per cent. of strength at a temperature of 500°, and is wholly unsuitable on this account for conveying superheated steam (1522). Cast-iron has also been condemned for super-heaters (1350). The use of steel ought to be discouraged for the heating surfaces of super-heaters (B.T. Rule 105); such pipes ought to be of wrought iron.

DIMINUTION OF STRENGTH OF COPPER AT DIFFERENT TEMPERATURES.

Experiments by the Franklin Institute.

Temperature F.	Tenacity in tons per square inch.	Temperature F.	Tenacity in tons per square inch.
122	14·73	801	8·48
302	13·84	1016	4·95
545	11·16	2032	0·0

During the process of brazing, copper is in danger of losing its ductility owing to the extraction of oxygen, and many cases of explosion are attributed to this cause (1968). In case 1839 it was pointed out that the use of the dioxydising blue flame of a blow-pipe for repairing a copper pipe makes it brittle. Report 1969 refers to a case of explosion of the brazed seam of a copper pipe. A special

report was made upon this case by Professor Henry Louis, of Armstrong College, Newcastle-on-Tyne, and will be found appended to the Board of Trade report. He says:—

"Two points deserve special attention—(1) The braze was unusually thick, having the thickness of $\frac{1}{8}$ inch in places. (2) The braze was so placed as to form the lowest portion of the steam pipe; any water condensed in the pipe would therefore lie upon the braze, and such water might contain in solution small quantities of salt, mainly chloride organic acids, &c., and would be at a high temperature, and under considerable pressure it would have considerable solvent power and would be capable of corroding the brazing material."

He adds the following suggestions for future precautions in brazing pipes:—

(1) The spelter for brazing should be quite free from lead.
(2) During the brazing a reducing atmosphere should be avoided.
(3) The brazed pipes should be cooled as rapidly as possible.
(4) The braze should be kept as thin as possible.
(5) The braze should form the topmost portion of the steam pipe when the latter is in position.

He further adds:—

"It need hardly be added that all risk of this nature would be avoided by the use of solid drawn instead of brazed steam pipes, so that there would appear to be no good reason why the latter should ever be employed."

The subject of brazed piping came before three Commissioners in case 1033, and after an exhaustive inquiry the following opinion was given:—

"Our own opinion is that in view of the high steam pressure now in use, which will probably still further increase in the near future, lap welded wrought iron pipes or seamless steel pipes as

now manufactured are distinctly preferable either to brazed or seamless copper pipes. We are not aware of any method by which defects in the brazing of copper, or defects due to the overheating of the same, can be readily detected. We are of the opinion that brazed copper steam pipes $3\frac{1}{2}$ inches in internal diameter and over should be examined periodically with their lagging removed and tested by hydraulic pressure, and that they should be subjected to this examination and test at intervals *not exceeding about four years.* The test pressure should be such as would subject the material of the pipe to a stress of $2\frac{1}{2}$ tons per square inch on the sectional area of the material, provided that the thickness of the pipe is not less than that given by the Board of Trade rule for copper steam pipes as stated in the 1896 copy of Instructions to Surveyors.

"We are of opinion that the risk of explosion of copper steam pipes would be materially reduced by hooping them with wrought iron or steel bands, or by serving them with wire as has been adopted in some cases.

"In conclusion, having regard to the numerous failures of copper steam pipes, and to the reports of casualties resulting therefrom which have been brought to our notice by the Board of Trade, we desire to say that the owners or users should be urged to carry out reasonably frequent examination and testing of existing copper steam pipes exposed to high steam pressure; and that in the case of new work they should be recommended to adopt lap-welded wrought iron or seamless steel pipes, properly arranged with carefully designed expansion joints and with means to prevent such joints from blowing out."

Copper pipes of material formed by the electro-depositing process lack ductility, and have frequently been condemned (1811). In report 1770 it was stated that copper pipe material ought to be tested for ductility to an elongation of 40 per cent. before fracture and a tensile stress of $13\frac{1}{2}$ tons to the square inch.

Bronze lacks ductility and a flexible pipe of this material became fatigued by the pulsations caused by the intermittent withdrawal of steam from a pipe by a pumping engine, causing a crack to be developed and the ensuing explosion (1648).

F. Bad Joints and Miscellaneous Causes.

Manhole or Sludge Door Joints.—A common cause of disaster in the working of a boiler is the blowing out of some joint due to ill-fitting covers or badly made joints. The manhole covers and sludge doors of a boiler require careful fitting and careful jointing. A loose fitting cover is a very grave danger. The door or cover, fitting loosely, may not be fixed centrally so that the jointing on one side, having too little support, is blown out (1835). It should therefore always fit perfectly, and $\frac{1}{4}$ or $\frac{3}{8}$ inch clearance is dangerous (1723), (1769).

The form and the material of the packing is a subject of considerable importance. The joint ought to be of a flat section, as a round joint is more apt to be blown out (447). It must also be even all round, else the screwing up of the bolts will create an uneven pressure and cause severe stresses in the flange (1212). And although the joint must be thick enough to make up for the unevenness between the surfaces of the flange and the manhole door (1664), they must not be so thick as to present a considerable surface to the steam pressure. The jointing material ought to cover the whole of the flange, both inside and outside the bolt circle, as the making of a joint inside the bolt circle alone may cause undue stress in the flange and result in fracture (1942).

In report 1664 the Commissioners pointed out the danger of getting an uneven bearing on the flange, and recommended that manhole and sludgehole doors should be fixed in place and examined both from inside and outside the boiler before the packing was used and also before rejointing in order to see the thickness of jointing required.

With regard to the material of the joint, the question as to whether rubber is a suitable material came before

the Commissioners this year (2071). They said that they concurred in the views of the Commissioners who made report 790, relating to the failure of an indiarubber ring, who said they were not prepared to say that indiarubber was an unsuitable material for joints, and added:—

"We have ascertained that it is used almost exclusively for this purpose in this district (Stoke-on-Trent), as it is in many other places without ill-effect. At the same time, we are of the opinion that the use of a substance of less perishable nature would make a joint more secure, and we should prefer to see its use adopted."

The use of spun yarn is not altogether satisfactory as it is apt to be uneven (356), and canvas rolled up with some adhesive substance proved to be a bad joint in case 2104.

If, as is usual, the door is on the inside of the boiler, the pressure in the boiler will reduce the thickness of the joint and necessitate the tightening up of the bolts as the pressure rises. Failure to tighten up caused disaster (2100), but on the other hand excessive tightening combined with an uneven joint is also dangerous (1794).

Many accidents have been caused by the loosening of bolts of the manhole or mudhole while the steam pressure is still on the boiler (338). Accidents have also been caused by opening the manhole door when the boiler is cold. The steam is condensed in the boiler, thus causing a vacuum, and as soon as the door is loosened it is blown in by atmospheric pressure. Before loosening the bolts of manholes it is desirable therefore to open the safety-valve and drain cock of the water-gauge to ensure equal pressure inside and out.

Cast-iron is not a suitable material for manhole or sludge-hole doors (1794).

Other causes of explosion are the following:—

Ice and Ice Pressure.—The stoppage of circulation in heating apparatus by ice is a common cause of explosion

in a boiler (usually of C.I.) unprovided with a safety-valve (1226). The immediate cause of explosion was over-pressure due to lack of circulation, causing steam to be generated and pressure due to the expansion of water in a closed vessel.

The expansion of ice causing pressure may lead to fracture. In case 252 water left in the shell of the firebox of a vertical boiler froze, and by expansion caused a crack in the shell. (Table of expansion of ice, p. 105.)

Gas Pressure. — *Economiser.*—The gases from the flues passing from the boiler through the chamber came into contact with an overheated economiser, which ignited the gases and wrecked it (1687). The force of such explosion could not have been very great, but the economiser was in a defective condition.

The overheating of economisers may arise from (i.) neglecting to clean them; (ii.) shutting off feed supply and leaving dampers to the economiser chamber open.

Coal Tar Still.—Several explosions due to ignition of gas have occurred owing to negligence by inserting a red hot rod (8), leaving a cock open (38), leaving a light in the cooler (71).

Oil Still.—Report 1424 deals with an explosion due to pumping oil into a still which had become overheated while the still was open to the atmosphere, causing the oil to vapourise, ignite and explode, whilst excessive gas pressure from a similar cause resulted in explosion (1067), (2085).

Hydrostatic Pressure.—In the case of a devulcaniser containing rubber, water and caustic soda, fitted with a steam jacket, it was found that the explosion was due to hydrostatic pressure caused by filling the vessel too full (2068).

The expansion of water by rise of temperature is given in column 2 of the Table on p. 105.

The Commissioners recommended a safety-valve to relieve hydrostatic pressure, or a "fool-proof" method of filling the vessel so that the height of the liquid could never rise above a fixed safe level. The case reported 1862A (see p. 35) most probably was due to hydrostatic pressure.

Multiple Explosion.—The force of the explosion of one boiler may cause the explosion of others either by the vibration set up or by the impact of pieces of the shell. Three such cases have been reported, one in which seven boilers exploded (1948), others in which three and eleven exploded respectively (116), (873).

The shock of the explosion of a tube of an economiser also caused three other tubes and the top of the box to fracture (1856).

Stopping Leaks under Pressure.—Caulking leaking seams under pressure is highly dangerous, and, though there is no reported case where this has actually been the cause ascribed for the explosion, Mr. Longridge gives, as his opinion, this cause for the explosion dealt with in report 574.

Tightening up the bolts of economiser caps when under pressure has been the cause of several explosions (1371), (1692), (2036). In the last case the Commissioners called attention to the fact that where the cap is only secured by two bolts, if one of the bolts fail either owing to its own defect or to the overstraining when tightening the nuts, the cover must be blown off when the economiser is under pressure. They endorsed the view of the Engineer-Surveyor-in-Chief of the Board of Trade that there ought

to be conspicuous notices warning attendants not to tighten up the bolts of caps while the apparatus is under pressure. It was further stated that the firm of economiser manufacturers had decided (after June, 1910) to supply all economisers with four instead of two bolts.

Section 4

EVIDENCE OF CAUSES OF EXPLOSION

The ascertainment of the cause of an explosion may be simple or complex. On the one hand the explosion itself may furnish direct proof of the cause, whilst on the other, it may be such as to give rise to various theories.

To support any theory, evidence must be gathered either from experience of similar accidents or from the circumstances of the particular case. The preceding section deals with Board of Trade experience, and in this section it is proposed to deal with the evidence which may be adduced from the circumstances of any explosion. Such evidence may be supplied or corroborated in four ways:

(i.) From the history of the boiler.

(ii.) From an account of the incidents immediately preceding the explosion.

(iii.) From examination of the fractured boiler after explosion.

(iv.) From tests of material, &c., after the explosion.

(i.) **Evidence from the History of the Boiler.**—The most important facts in the history of a boiler are those referring to the manufacture, management, repairs, inspection and tests.

Details of the manufacture sometimes reveal facts which account for a flaw or weakness in the material or joint of a boiler.

The British standard specification for marine boilers calls for steel manufactured by the open-hearth process,

and evidence of any other form of manufacture would raise a presumption of inferiority, though this might be rebutted by evidence of satisfactory tests.

Evidence that the rivet holes have been punched, especially if punched before the plates were bent, would give rise to a possible cause of fracture near or through the line of rivet holes (265). (Also see B.T. Rule 98.)

B.T. Rule 104 reads:

> "All plates that have been punched, flanged or locally heated, also all stays or stay tubes which have been locally heated, should be carefully annealed after being so treated."

Evidence that these had not been annealed would be strong evidence of incipient brittleness.

On one occasion the use of an hydraulic rivetter in the manufacture was found to be the cause of a crack developing in the dished end of a waterdrum (1699), whilst details of the process of brazing have caused Commissioners to come to the conclusion that defects existed when the pipes left the manufacturer (1033).

Improper acts or omissions in management of the boiler is strong evidence that the defect which caused explosion resulted after it came under that management. The acts of management which have caused explosion are contained throughout section 3 and require no further comment.

The history of repairs is important. If in a comparatively short life a boiler has required constant repair, it indicates one of two causes: either that the boiler was incipiently weak, or that the management of it was improper. Here again the question must be tested by experience of what good and bad management is. If there has been no possible cause for repairs due to bad management it may be urged that weak construction caused repairs, and also the subsequent explosion. This view, however, would

require corroboration by tests of the material, as described hereafter.

Inspection of the boiler by a competent engineer prior to the explosion is not conclusive evidence that no defect was present at the time of the inspection. Either the inspection may not have been carried out very thoroughly, or if thorough, may fail to detect defects. On the other hand, inspection which has discovered defects, which at the time of the explosion are still unrepaired, is a strong indication that the defects then existing caused the explosion, provided that the evidence of the results of the explosion corroborate it.

Hydraulic tests prior to the explosion afford some evidence of the quality of material and construction, provided that the test has been carried out satisfactorily and has not been so severe as in itself to cause straining of the boiler. The danger of hydraulic tests is that if the pressure under it is very high the boiler may by it become overstrained and weakened. The Commissioners in report 1301 said:—

> "We have formed the opinion that the water test . . . should always be used with great care, and moreover by competent persons, and should never be used higher than twice the working pressure of the boiler, lest in attempting to discover a defect the boiler might be overstrained and weakened."

The evidence of hydraulic tests is, however, *by no means conclusive* that the boiler was without defect. In report 1699 the Commissioners found that the test of 240 lbs. per square inch hydraulic dead load did not show incipient cracks, which increased and caused ultimate failure, when a live load of 160 lbs. per square inch steam pressure was applied.

On p. 48 of Mr. Longridge's report for 1910, an instance is given of a water-tube boiler withstanding an hydraulic test of 120 lbs. per square inch when the plates between

the pipes leading to the steam dome and the back end of the drum had wasted so that the thickness was no greater than from $\frac{1}{16}$ inch to that of brown paper.

B. T. Rules 87 (last paragraph) and 115 deal with hydraulic tests. The limit of pressure is fixed at twice the working load, and no test is to be considered satisfactory unless the boiler has borne the test pressure for at least ten consecutive minutes.

(ii.) **Evidence from the incidents preceding Explosion.**—A great deal of the evidence of the cause of explosion may usually be adduced from the incidents just before the explosion. Thus, for example, overpressure may be evidenced by testimony that the pressure-gauge registered excessive pressure before the explosion, or that the safety-valves failed to act. Overheating due to hardfiring may be evidenced by testimony that the draught was very great, or that the boiler was priming violently (1475). Overheating due to shortness of water may be evidenced by testimony that the water-gauge was empty or stopped up, or that the check-valve, blow-off cock or seams of the boiler leaked, or that the feed pump was out of order. Weakness may be evidenced by testimony that there was leakage through the plates before explosion (1699). Waterhammer may be evidenced by testimony that the boiler was priming and that there was water in the pipes, and that, on opening the stop valve, a noise of knocking was heard.

All this evidence is fairly direct, and other similarly straightforward evidence may be gathered from the incidents of the day, which is conclusive if borne out by subsequent examination.

The amount of noise of the explosion also may be of importance. This depends upon the violence of the ex-

plosion (*i.e.*, the amount of energy released by it). As will be seen from the table on p. 94 a cubic foot of water has about twenty times the energy of a cubic foot of steam; therefore if the water in the boiler is very low, the noise of explosion will be comparatively small (583).

(iii.) **Evidence from the Examination of the Fractured Boiler.**—This is often the most important and conflicting evidence of all. It may be divided under the following heads:

(i.) The disposition of the fractured pieces.
(ii.) The appearance of the fractures.
(iii.) Other indications of cause of failure.

The disposition of the fractured pieces is a good indication of the violence of the explosion which depends (*a*) upon the pressure in the boiler, and (*b*) upon the quantity of water in the boiler. As stated above a cubic foot of water liberates about twenty times more energy than a cubic foot of steam. Therefore a filled boiler will explode with greater violence than one short of water.

In case 1638 a piece of a boiler weighing two tons was blown 234 yards with a pressure in the boiler of only 49 lbs.

The table on p. 94 gives the energy in foot-tons liberated by the fall of pressure of steam and water respectively to atmospheric pressure.

The appearance of the fractured surfaces of the boiler often gives strong indications of the cause of fracture.

Flaws in the material, however, are only visible shortly after fracture, because oxidation of the newly fractured surfaces reduces them to the same dulness as the flaw. If, however, the surfaces are examined soon after fracture, a flaw of appreciable dimensions can be detected by an appearance of dulness or corroded surface.

Pressure.	Temperature.	Energy liberated by fall of pressure to atmospheric pressure.	
		By 1 cubic foot of water.	By 1 cubic foot of steam.
Lbs. per sq. in.	Fahr.	Foot-tons.	Foot-tons.
25	240°	12	0·8
50	281°	71	3·7
75	307°	135	7·1
100	327°	193	10·9
150	358°	292	18·2
200	381°	391	28·6
250	401°	482	83·5

The above table is compiled from the table on p. 194 of the "Practical Engineer" Pocket book.

The quality of material can also be estimated from the appearance of the fracture.

The following statements in this respect are taken from Kirkcaldy's "Experiments on Wrought Iron and Steel," p. 52:—

"(1) Whenever wrought iron breaks suddenly a crystalline appearance is the invariable result; when gradually, invariably a fibrous appearance.

"(2) Whether, on the one hand, it is finely or coarsely crystalline, or on the other, the fibre be fine and close, or coarse and open, *depends upon the quality of the material.*

"(3) When there is a combination of two kinds—the one harder or less ductile than the other—the appearance will be partly crystalline and partly fibrous; the latter produced by the gradual drawing asunder action previous to and at the time of rupture; whilst in the former the iron breaks suddenly, without elongating at the time of rupture.

"(4) When the proportion of the harder is considerably less than the softer, the former snaps suddenly, whilst the latter continues stretching; but when nearly equal, or the less ductile predominates, both portions break together or almost at the same

moment—the one part, gradually arriving at its limit of endurance, breaks with a fibrous appearance whilst a greatly increased strain consequently coming on the remaining portion, it suddenly gives way, producing a crystalline appearance."

"(5) The relative qualities of various irons may be pretty accurately judged by comparing fractures, provided they have all been treated in precisely the same way and all broken under the same sort of strains similarly applied."

"(6) By varying either the shape, the treatment, the kind of strain or its application, pieces cut off the same bar will be made to present vastly different appearances in some kinds of iron, whilst in other little or no difference will result."

Speaking of steel, on p. 62, Mr. Kirkcaldy found that:

"The conclusions respecting wrought iron are equally appropriate to steel, viz., wherever rupture occurs slowly, a silky fibrous, and when suddenly, a granular appearance is invariably the result, both kinds varying in fineness according to quality. The surface in the latter case is even and always at right angles to the length, in the former angular and irregular in outline. The colour is a light pearl-grey slightly varying in shade with the quality; the granular fracture almost entirely free from lustre, and consequently totally unlike the brilliant crystalline appearance of wrought iron."

From these statements, the following conclusions may be drawn:

(i.) The fracture ought to be uniform whether it be crystalline or fibrous.

(ii.) When fibrous the fibres ought to be close and fine.

(iii.) When crystalline the crystals ought to be small and uniform.

(iv.) If the section is not uniform it indicates that some of the fibres have been softer than others.

An indication strongly in favour of the cause of explosion being over-pressure and not weakness, is that the rivets or plates have been pulled out of shape before fracture. This shows that they had ductility before fracture, and did not

break until the pressure upon them became great. A brittle material caused by defective manufacture or improper treatment will snap off sharply on rupture.

Other indications of cause of failure obtained by examination are the following:—

Corrosion.—This can be easily seen, and it is only a question of degree as to whether the corrosion has been sufficient to cause the explosion.

Overheating.—Clear signs of overheating are those showing that the plates or tubes have been greatly distorted gradually under pressure. A furnace tube collapsing inwards, or a water tube greatly increasing in diameter before fracture, is strong evidence. A discoloration of the metal due to being red-heated may also be expected. If the alloy of metal in the fusible plug has melted, although it has failed to be blown out by reason of the cavity being filled with scale, there is evidence of overheating. The marks of water-level below the crowns of the furnace also give evidence of shortness of water, whilst the examination of the connections of the water-gauge may show that the gauge has been choked up.

Deposit causing overheating may be found on the tubes, although its absence is not conclusive against this theory of explosion, as the force of the explosion may blow it away (1842). On the other hand scale and soot at the exact point of collapse would point to the plate not having been red-hot (1825). Over-heating from grease does not necessitate the finding of a great deal of grease on the plates of the boiler. It requires only a very slight film of grease (such as would "dirty one's clothes") to cause overheating, and the film of grease disappears altogether from the collapsed parts. (Stromeyer, "Marine Boiler Management and Construction," p. 31.)

Weakness.—Indications of grooving due to fatigue may also be found by seeing whether the plates show sign of wear in the parts which have fractured.

Abnormal Steam Pressure.—The examination of safety appliances may show that they are out of working order, which would result in abnormal steam pressure. Where a boiler is fitted with more than one safety-valve it would be necessary to show that both valves had been inoperative, and such view would be corroborated by finding that the pressure gauge had been put out of gear (1601). But it must be borne in mind that where a safety-valve is severed in the general break-up of the boiler, the obstruction to its working may be blown out.

In cases of boilers fitted with reducing valves or relief pipes, indications that the one was inoperative or that the other was choked or shut, would be strong evidence in favour of abnormal steam pressure. Where there has been abnormal steam pressure causing one part of the boiler to give way, it is to be expected that the boiler gave way in its weakest part, and if there is any other seam or joint of the boiler which by calculation had only the same strength, there should be signs of straining or bulging or general deformation in that part.

(iv.) **Evidence from Tests of the Material.**—Tests made after the explosion are most important where any question arises as to whether the boiler has deteriorated by use or whether the material of which it was originally constructed was defective. Test pieces are taken from the metal immediately near the fracture; from the metal away from the fracture, and also samples of rivets. These test pieces may then be subjected to certain mechanical tests.

As tenacity and ductility are the two most important characteristics of boiler metal—the first to withstand

pressure, and the second to take up variations in pressure without fatigue—the tests to which the metal ought to be subjected are a *tensile test* to prove the breaking strength of the material and to ascertain its percentage elongation before fracture, and *bending and hammering tests,* to prove its ductility. The composition of the material may be proved by analysis.

The comparison between the tests made upon the metal of the exploded boiler and the standard metal of good quality may indicate various causes of explosion.

If the samples taken from near the fractured surface alone fall far short of the standard tests, the implication is (i.) that the metal in that part of the boiler has become fatigued by strain set up by improper management or overheating (*e.g.* 2003), or (ii.) that, in the case of a boiler plate, it was punched and not properly restored to its ductile condition by annealing.

If the samples taken from other parts of the boiler also show bad results as compared with the standards, it may be urged that the material of the whole boiler was defectively manufactured. On the other hand, Mr. Stromeyer points out in his memorandum to the M.S.U.A., 1908, that mild steel possesses *ageing properties,* and gives various examples of boiler plates which have become brittle by age.

If rivets alone show bad results the presumption would be either (i.) that they were made of inferior material, (ii.) that they had been initially strained by being riveted under too great a pressure, or (iii.) that they alone had become fatigued by straining due to expansion and contraction.

Standard Tests of Boiler Material.—The following table compiled from various authorities (quoted) gives the breaking strengths of materials and percentage elongation or contraction of cross-section of material of good quality:—

APPENDIX A

BOILER EXPLOSIONS ACT, 1882.

45 & 46 *Vict. c.* 22. *An Act to make better provision for Inquiries with regard to Boiler Explosions.* [12th July, 1882.]

Whereas special provision has been made by law for making inquiry into the causes and circumstances of boiler explosions on board ships and on railways, and it is expedient that like provision be made for making inquiries with respect to boiler explosions in other cases :

Be it therefore Enacted as follows :

1. This Act may be cited as the Boiler Explosion Act, 1882.

2. This Act shall extend to the whole of the United Kingdom.

3. In this Act the term "boiler" means any closed vessel used for generating steam, or for heating water or for heating other liquids, or into which steam is admitted for heating, steaming, boiling, or other similar purposes.

The term "Court of Summary Jurisdiction" means any justices of the peace, metropolitan police magistrate, stipendiary magistrate, sheriff, sheriff substitute, or other magistrate or officer, by whatever name called, who is capable of exercising jurisdiction in summary proceedings for recovery of penalties.

4.—This Act shall not apply to any boiler used exclusively for domestic purposes; or to any boiler used in the service of Her Majesty, or to any boiler on board a steamship having a certificate from the Board of Trade, or to any boiler explosion into which an inquiry may be held under the provisions of the Coal Mines Regulations Act, 1872, and the Metalliferous Mines Regulation Act, 1872, or either of them.

5.—(1.) On the occurrence of an explosion from any boiler to which this Act applies, notice thereof shall, within twenty-four hours thereafter be sent to the Board of Trade by the owner or user, or by the person acting on behalf of the owner or user.

(2.) The notice shall state the precise locality as well as the

day and hour of the explosion, the number of persons injured or killed in addition to the purposes for which the boiler was used, and, generally, the part of the boiler that failed and the extent of the failure, and such other particulars, if any, as the Board of Trade by notice inserted in the London Gazette may require, and shall be in the form printed in the schedule to this Act, or in such other form as the Board of Trade may from time to time approve for the purpose.

(3.) If default is made in complying with the requirements of this section, the person in default shall, on summary conviction, be liable to a fine not exceeding twenty pounds.

6.—(1.) On receiving notice of a boiler explosion the Board of Trade may, if it thinks fit, appoint one or more competent and independent engineer or engineers, practically conversant with the manufacture and working of boilers, to make a preliminary inquiry with respect to the explosion, and the persons so appointed shall have the powers conferred on the court by sub-section (4) of this section. If it appears to the Board of Trade either upon or without such preliminary inquiry, that a formal investigation of the causes and circumstances attending the explosion is expedient, the Board of Trade may direct a formal investigation to be held; and with respect to such investigation the following provisions shall have effect.

(2.) Formal investigations of boiler explosions shall be made at or near the place of such explosion by a court consisting of not less than two commissioners appointed by the Board of Trade, of whom one at least shall be a competent and practical engineer, specially conversant with the manufacture and working of steam boilers, and one a competent lawyer. The court shall be presided over by one of the commissioners, the selection being made by the Board of Trade.

(3.) Any such formal investigation shall be held in open court, in such manner, and under such conditions, as the commissioners may think most effectual for ascertaining the causes and circumstances of the explosion, and for enabling them to make the report hereinafter mentioned in this section.

(4.) The court shall have, for the purpose of its investigations, all the power of a court of summary jurisdiction when acting as a court in the exercise of its ordinary jurisdiction and shall in addition have the following powers, viz.:

(*a*) The court, or any one appointed by it, may enter and inspect any place or building the entry or inspection whereof appears to the court requisite for the said purpose.

(*b*) It may by summons under its hand require the attendance of all such persons as it thinks fit to call before it, and examine for the said purpose, and may for such purpose require answers or returns to such inquiries as it thinks fit to make.

(*c*) It may require and enforce the production of all books, papers, and documents which it considers important for the said purpose.

(*d*) It may administer an oath and require any person examined to make and sign a declaration of the truth of the statements made by him in his examination.

(*e*) Every person so summoned, not being the owner or the user of the boiler or in the service or employment of the owner or user, or in any way connected with the working or management of the boiler, shall be allowed by the Board of Trade such expenses as would be allowed to a witness attending on subpœna before a court of record, and in Scotland to a witness attending any criminal trial by jury in the sheriff court: and in case of dispute as to the amount to be allowed, the same shall be referred by the court to a master of the superior courts, and in Scotland to the auditor of the Court of the Session, who on request under the hands of the members of the court, shall ascertain and certify the proper amount of such expenses.

(5.) The court making a formal investigation with respect to any boiler explosion shall present a full and clear report to the Board of Trade, stating the cause of the exposion and all the circumstances attending the same, with the evidence, adding thereto any observations thereon, or on the evidence, or any matters arising out of the investigation which they think right to make, and the Board of Trade shall cause every such report to be made public in such a manner as it thinks fit. When no formal investigation is held, the report presented to the Board of Trade by the engineer making a preliminary inquiry with respect to a boiler explosion shall be made public in such manner as the Board of Trade thinks fit.

7. The court may order the costs and expenses of a preliminary inquiry or formal investigation or any part thereof, including therein the remuneration of persons holding such inquiry or investigation, to be paid by any person summoned before it, or by the Board of Trade, and such order shall, on the application of any party entitled to the benefit of the same, be enforced by any court of summary jurisdiction as if such costs and expenses were a penalty imposed by such court. The Board of Trade may, if they think fit, pay to the person holding any inquiry or investigation under this Act such remuneration as they may, with the consent of the Treasury appoint.

If and so far as not otherwise provided for, all costs and expenses incurred by the Board of Trade, including any remuneration paid under this section, and any costs and expenses ordered by the court to be paid by the Board of Trade, shall be paid out of monies to be provided by Parliament.

8. Any fine payable under this Act shall be recovered in England in the manner provided by the Summary Jurisdiction Acts, in Scotland in the manner provided by the Summary Jurisdiction Acts, 1864 and 1881, and of any Act or Acts amending the same, and in Ireland within the police district of Dublin metropolis in accordance with the provisions of the Act regulating the powers and duties of justices of the peace for such district, or of the police of such district elsewhere in Ireland in accordance with the provisions of the Petty Sessions (Ireland) Act, 1851 (14 & 15 Vict. c. 93) and any Act amending or affecting the same.

SCHEDULE.

Report of explosion of a steam boiler to be sent to the Board of Trade within twenty-four hours after the occurrence of an explosion.

1. Name of premises or works on which the boiler had exploded.
2. Address by the post.
3. Day and hour of explosion.
4. Number of persons killed.
5. Number of persons injured.
6. General description of the boiler.
7. Purpose for which the boiler was used.
8. Part of the boiler which failed, and the extent of failure generally.

9. Pressure at which the boiler was worked.
10. Name and address of any society or association by whom the boiler was last inspected or insured.

Signature of the person responsible for the accuracy of the particulars contained in this form.

Address :

Date :

BOILER EXPLOSIONS ACT, 1890.

53 & 54 *Vict. c.* 35. *An Act to amend the Boiler Explosions Act*, 1882. [4th August, 1890.]

Be it Enacted as follows :

1. This Act may be cited as the Boiler Explosions Act, 1890, and this Act, and the Boiler Explosions Act, 1882, may be cited together as the Boiler Explosions Acts, 1882 and 1890.

2. So much of section four of the Boiler Explosions Act, 1882, as relates to any boiler other than a boiler used in the service of Her Majesty, or used exclusively for domestic purposes, is hereby repealed, and the said Act shall apply in the case of any boiler explosion occurring on board a British ship.

3. In the case of an explosion occurring at sea, the notice required by section five of the Boiler Explosions Act, 1882, shall be sent by the owner or master of the ship and shall be sent within twenty-four hours after the occurrence of the explosion, or as soon thereafter as possible ; but this provision shall not apply where a report of the explosion has been duly sent in pursuance of section three hundred and twenty-six of the Merchant Shipping Act, 1854.

4. Every person who refuses to attend as a witness after having been required so to do in the manner specified in section six of the Boiler Explosions Act, 1882, and after having had a tender made to him of the expenses therein mentioned, or who refuses or neglects to make any answer or to give any return, or to produce any documents in his possession, or to make or subscribe any declarations required under the powers of the said Act, shall for each such offence be liable to a fine of not exceeding ten pounds, recoverable as therein provided.

APPENDIX B

TABLE OF SATURATED STEAM PRESSURES WITH CORRESPONDING TEMPERATURES (Fahr. and Cent.).*

Pressure Absolute. Pounds per square inch.	Temperature.		Pressure Absolute. Pounds per square inch.	Temperature.	
	Fahr.	Cent.		Fahr.	Cent.
14·7	212	100	170	368	187
20	228	109	180	373	190
30	250	121	190	377	192
40	267	131	200	382	194
50	281	137	210	386	197
60	292	144	220	390	199
70	303	151	230	394	201
80	312	156	240	397	203
90	320	160	250	401	205
100	328	164	260	404	207
110	334	168	270	408	210
120	341	172	280	411	210
130	347	175	290	414	212
140	353	179	300	417	214
150	358	181	350	430	221
160	363	184	400	445	230

* This Table has been compiled from the tables given in the "Steam Engine and Gas and Oil Engines," by Prof. John Perry, F.R.S. (Macmillan), and has been inserted by permission.

INCREASE IN VOLUME OF WATER AND ICE FROM WATER AT 4° C.

Ice.		Water.	
Temperature below zero C.	(1) Percentage increase in volume from volume of greatest density, viz. : 4° C.	Temperature above zero C.	(2) Percentage increase in volume from volume of greatest density, viz. : 4° C.
0	0·06	4	0
—5	0·14	20	0·17
—10	0·22	30	0·42
—15	0·30	40	0·77
—20	0·38	50	1·20
—25	0·46	60	1·69
—30	0·54	70	2·26
		80	2·89
		90	3·57
		100	4· 3
		110	5· 1
		120	6· 0
		130	7· 0
		140	8· 1
		150	9· 2
		160	10· 3
		170	11· 6
		180	12· 9
		190	14· 3
		200	15· 7
		210	17· 2

(1) Professor Plucker, Encyl. Brit., Section "Ice."

(2) This table is extracted, with permission, from the "Steam Engine and Gas and Oil Engine," by Prof. John Perry, F.R.S. (Macmillan).

APPENDIX C

BOARD OF TRADE RULES, 87 AND 124.*

Cylindrical Boilers.—87. The Board of Trade consider that boilers well constructed, well designed, and made of good material should be allowed an advantage in the matter of working pressure over boilers inferior in any of the above respects, as unless this is done the superior boiler is placed at a disadvantage, and good workmanship and material will be discouraged. They have therefore caused the following rules to be prepared:—

When the cylindrical shells of boilers are made of the best material, with all the rivet holes drilled in place and all the seams fitted with double butt straps each of at least five-eighths the thickness of the plates they cover, and all the seams at least double-riveted with rivets having an allowance of not more than 75 per cent. over the single shear, and provided that the boilers have been opened to inspection during the whole period of construction, then 5 may be used as the factor of safety. The tensile strength of the iron is to be taken as equal to 47,000 lbs. per sq. in. with the grain, and 40,000 lbs. across the grain. If, however, the iron be tested and the elongation measured in a length of 10 ins. is not less than 14°/₀ with and 8°/₀ across the grain, and the Surveyors are otherwise satisfied as to the quality of the plates and rivets, 4·5 may be used as the factor of safety instead of 5, in which case the minimum actual tensile strength of the plates should be used in calculating the working pressure. When the above conditions are not complied with, the additions in the following scale should be made to the factor of safety according to the circumstances of each case:—

A†	·15	To be added when all the holes are fair and good in the longitudinal seams, but drilled out of place after bending.

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* Reproduced by permission of the Controller of His Majesty's Stationery Office.

B†	·3	To be added when all the holes are fair and good in the longitudinal seams, but drilled before bending.
C	·3	To be added when all the holes are fair and good in the longitudinal seams, but punched after bending.
D	·5	To be added when all the holes are fair and good in the longitudinal seams, but punched before bending.
E*	·75	To be added when all the holes are not fair and good in the longitudinal seams.
F	·1	To be added if the holes are all fair and good in the circumferential seams, but drilled out of place after bending.
G†	·15	To be added if the holes are fair and good in the circumferential seams, but drilled before bending.
H	·15	To be added if the holes are fair and good in the circumferential seams, but punched after bending.
I†	·2	To be added if the holes are fair and good in the circumferential seams, but punched before bending.
J*	·2	To be added if the holes are not fair and good in the circumferential seams.
K	·2	To be added if double butt straps are not fitted to the longitudinal seams, and the said seams are lap and double-riveted.
L	·1	To be added if double butt straps are not fitted to the longitudinal seams, and the said seams are lap and treble-riveted.
M	·3	To be added if only single butt straps are fitted to the longitudinal seams, and the said seams are double-riveted.
N	·15	To be added if only single butt straps are fitted to the longitudinal seams, and the said seams are treble-riveted.
O	1·0	To be added when any description of joint in the longitudinal seams is single-riveted.
P	·1	To be added if the circumferential seams are

		fitted with single butt straps and are double-riveted.
Q	·2	To be added if the circumferential seams are fitted with single butt straps and are single-riveted.
R	·1	To be added if the circumferential seams are fitted with double butt straps and are single-riveted.
S†	·1	To be added if the circumferential seams are lap and are doubled-riveted.
T	·2	To be added if the circumferential seams are lap and are single-riveted.
U	·25	To be added when the circumferential seams are lap and the strakes of plates are not entirely under or over.
V‡	·3	To be added when the boiler is of such a length as to fire from both ends, or is of unusual length, as in the case of flue boilers, and the circumferential seams fitted as described opposite P, R, and S, but when the circumferential seams are as described opposite Q, and T, V ·4 should be added.
W*	·4	To be added if the longitudinal seams are not properly crossed.
X*	·4	To be added when the iron is in any way doubtful, and the Surveyor is not satisfied that it is of the best quality.
Y††	1·65	To be added if the boiler is not open to inspection during the whole period of its construction.

When marked * the factor may be increased still further if the workmanship or material is such as in the Surveyor's judgment renders such increase necessary.

† When the holes are to be rimered or bored out in place, the case should be submitted to the Board as to the reduction or omission of A, B, G, and I, as heretofore.

‡ When the middle circumferential seams are double-strapped and doubled-riveted or lap- and trebled-riveted, and the calculated strength not less than 65% of the solid plate, S ·1 and V ·3 may be omitted. The end circumferential seams in such cases should be at least double-riveted.

†† When surveying boilers that have not been open to inspection during construction, the case should be submitted to the Board as to the factors to be used.

Area of Safety-Valves.—124. When natural draught is used the area per square foot of fire-grate surface of the locked-up safety-valves should not be less than that given in the following table opposite the boiler pressure intended, but in no case should the valves be less than two inches in diameter. This applies to new vessels and to vessels which have not previously received a passenger certificate.

When, however, the valves are of the common description, and are made in accordance with the table, it will be necessary to fit them either with springs having great elasticity, or to provide other means to keep the accumulation within moderate limits.

When forced draught is used, the area of the safety-valve should not be less than that found by the following formula:—

$$A \times \left\{ \frac{\text{Estimated consumption of coal per square foot of grate in lbs. per hour.}}{20} \right\} = \left\{ \begin{array}{c} \text{area of} \\ \text{valves} \\ \text{required.} \end{array} \right.$$

A = area of valves as found from the table.

When the pressure exceeds 180 lbs. per sq. in. the accumulation of pressure at the steam test will probably be exceptionally high, unless the area of the branch leading from the valve chest is in excess of the area of the valves and the area of the main waste steam pipe is correspondingly in excess of the gross area of the valves.

When ascertaining the fire-grate area, the length of the grate should be measured from the inner edge of the dead plate to the front of the bridge, and the width from side to side of the furnace on the top of the bars at the middle of their length.

In the case of vessels that have not previously had a passenger certificate, if there is only one safety-valve on any boiler, the Surveyor should not grant a declaration without first referring the case to the Board for special instructions.

Safety-Valve Areas

(Natural Draught).

Boiler Pressure.	Area of Valve per Square Foot of Fire Grate.	Boiler Pressure.	Area of Valve per Square Foot of Fire Grate.	Boiler Pressure.	Area of Valve per Square Foot of Fire Grate.
15	1·250	63	·480	111	·297
16	1·209	64	·474	112	·295
17	1·171	65	·468	113	·292
18	1·136	66	·462	114	·290
19	1·102	67	·457	115	·288
20	1·071	68	·451	116	·286
21	1·041	69	·446	117	·284
22	1·013	70	·441	118	·281
23	·986	71	·436	119	·279
24	·961	72	·431	120	·277
25	·937	73	·426	121	·275
26	·914	74	·421	122	·273
27	·892	75	·416	123	·271
28	·872	76	·412	124	·269
29	·852	77	·407	125	·267
30	·833	78	·403	126	·265
31	·815	79	·398	127	·264
32	·797	80	·394	128	·262
33	·781	81	·390	129	·260
34	·765	82	·386	130	·258
35	·750	83	·382	131	·256
36	·735	84	·378	132	·255
37	·721	85	·375	133	·253
38	·707	86	·371	134	·251
39	·694	87	·367	135	·250
40	·681	88	·364	136	·248
41	·669	89	·360	137	·246
42	·657	90	·357	138	·245
43	·646	91	·353	139	·243
44	·635	92	·350	140	·241
45	·625	93	·347	141	·240
46	·614	94	·344	142	·238
47	·604	95	·340	143	·237
48	·595	96	·337	144	·235
49	·585	97	·334	145	·234
50	·576	98	·331	146	·232
51	·568	99	·328	147	·231
52	·559	100	·326	148	·230
53	·551	101	·323	149	·228
54	·543	102	·320	150	·227
55	·535	103	·317	151	·225
56	·528	104	·315	152	·224
57	·520	105	·312	153	·223
58	·513	106	·309	154	·221
59	·506	107	·307	155	·220
60	·500	108	·304	156	·219
61	·493	109	·302	157	·218
62	·487	110	·300	158	·216

SAFETY-VALVE AREAS.—*continued.*

Boiler Pressure.	Area of Valve per Square Foot of Fire Grate.	Boiler Pressure.	Area of Valve per Square Foot of Fire Grate.	Boiler Pressure.	Area of Valve per Square Foot of Fire Grate.
159	·215	173	·199	187	·185
160	·214	174	·198	188	·184
161	·213	175	·197	189	·183
162	·211	176	·196	190	·182
163	·210	177	·195	191	·181
164	·209	178	·194	192	·181
165	·208	179	·193	193	·180
166	·207	180	·192	194	·179
167	·206	181	·191	195	·178
168	·204	182	·190	196	·177
169	·203	183	·189	197	·176
170	·202	184	·188	198	·176
171	·201	185	·187	199	·175
172	·200	186	·186	200	·174

APPENDIX D

[THE following has been inserted by the permission of the Manchester Steam Users' Association from the Report of the Chief Engineer, C. E. STROMEYER, Esq., for 1910.]

ADVICE TO BOILER ATTENDANTS.

STOKING, &c.

Raising Steam.—Before lighting fires see that there is sufficient water in the boiler, also watch the water-gauge while raising steam, for the blow-off valve or the feed check valve may be so leaky as to pass water as soon as there is any pressure. Large temperature differences in a boiler may produce fractures or start leakages. If the boiler cannot be filled with warm water through the economiser, then the firing should proceed very slowly so that the bottom of the boiler may grow as warm as the top. If pressed for time, the boiler may be filled to the top of the water-gauges, and when, with rapid firing, the top water has grown warm, discharge the cold bottom water and continue firing.

The Coal Bill for an average Lancashire Boiler is about £300 to £600 a year, and more than £100 can very easily be wasted by negligent stoking and by defects, which careful inspection by boiler experts can reveal. It is penny wise and pound foolish to ignore so-called trifles which waste fuel or heat during a whole year.

Dense Smoke indicates either that a boiler is overworked, that the draught is insufficient, or that the stoking is badly done. Light smoke indicates efficient stoking. With poor draught the fires should be kept thin and level by firing frequently, and at one side of the grate at a time. If necessary, keep the air grids in the fire doors slightly open just after coaling. A continuous

admission of much air is wasteful; it spoils the draught and merely dilutes the smoke, but does not remove the nuisance.

Mechanical Stoking may be as efficient as good hand stoking, especially with small coal, and pecuniary savings can then be effected if the cheapness of the fuel more than balances the wear and tear of the boiler and of the mechanical stoker. It is not advisable to use mechanical stokers with forced draught if the feed water is either sedimentary or greasy, for then the furnaces are almost sure either to bulge or to groove.

Bulged Furnaces.—The slow bulging which results from grease, scale, or concentrated impure waters, combined with intensely hot furnace temperatures, can only be stopped by removing its cause.

Collapses of Furnaces due to shortness of water are generally more sudden. Misreadings of the water level due to reflections from the glass shield, and dirt in the gauge-glass, frequently lead to these accidents, but negligence on the part of the stoker, stoppage of the feed supply, and leakages past the blow-off cock may also be the cause. As soon as shortness of water is discovered, cool the furnace plates from both sides as quickly as possible. Open the furnace doors to admit much cold air, but do not disturb the fires, ease the safety-valves, and close the stop valves of other connected boilers so as to cause priming in the neglected boiler. The rising froth will help to cool and stiffen the over-heated plates. All available feed should be turned on. Exhaustive experiments by this Association have shown that this procedure does not cause any increase of pressure.

Overhauling Boilers.

Boiler Inspection has now been made compulsory, and boiler owners are required to open out, scale and otherwise prepare their boilers in such a way that the Inspector can make a *thorough examination.*

Open out and clean the boiler sufficiently often in order that the scale may not grow too thick. Scale is most easily removed before it has come in contact with air. The boiler had therefore best be cooled with water in it and the scale scraped and brushed off as the water level is lowered. The flues should be cleaned

every three months or oftener. Improved boiler efficiency is obtained if the soot and tarry matter is brushed and scraped off the plates.

Manholes.—Before opening out a boiler, the safety-valve should be eased and kept open until the manhole and mudhole lids have been taken off, for if there is a pressure or a vacuum in the boiler the lid may be blown off the boiler or into it.

Fusible Plugs, if fitted, should be cleaned on the water side and on the fire side every time that a boiler is opened out. The fusible metal should be renewed on the occasion of the annual inspection.

Fittings.—All valves and cocks should be kept in a good working condition. They should be thoroughly overhauled on the occasion of the annual inspection, *except asbestos-packed cocks*, which should be overhauled only by the maker or an expert.

Safety-Valves and Low-Water Alarms should be eased daily to see that they are in working order and should be overhauled annually. It is a very *serious matter to overload safety-valves* or otherwise alter them. If they do not work properly the manager should be informed so that he may send for an Inspector to deal with the matter.

Corrosion.

Corrosion is generally due to air which has been absorbed by the feed water and which cannot be removed. Its action is intensified by common salt and by chlorides of magnesia and lime ; its action is diminished by suitable additions of soda and of lime. Purified water, in addition to obviating scale, also reduces corrosion. Excesses of soda or boiler compositions attack brass fittings and cause leaky seams.

Idle Boilers should be thoroughly washed out and dried. Trays with unslaked lime should be placed inside and the boilers should be closed air-tight. If the boiler is to stand ready for immediate use it should be filled with water to which burnt lime has been added, but unless the boiler is one of a battery and is kept warm, it is likely to condense atmospheric moisture from outside and corrode if filled with water.

Steam Pipes, &c.

Kiers and Steaming Vessels are by law defined as being boilers; it is therefore very desirable that they should be frequently inspected. *Steam pipes* should always be drained and kept dry, for it is *extremely dangerous* to admit steam into pipes in which water may be lodging. It is equally dangerous to drain pipes in which there is steam pressure, and yet without pressure it is difficult to drive water out of pipes when it has once got in. Pipes which are so arranged that water can lodge in them either with or without any valves being shut, should be provided with *steam traps* and these should *not be allowed to get choked.*

Cracking Noises in steam pipes indicate that they contain water and that an *explosion may occur* at any moment. Such cases should be carefully inquired into.

Warnings.

Don't overload the *safety-valves* or tamper with them.
Don't let the *water level* sink out of sight.
Don't allow the *cocks and valves* to set fast.
Don't open the steam *stop-valves* hurriedly.
Don't empty the boiler while steam is up.
Don't open manholes before easing safety-valves.
Don't raise steam hurriedly.
Don't use unknown *scale solvent* or compositions.
Don't slake ashes against boiler fronts.

[The following is a reproduction of instructions issued by the Vulcan Boiler and General Insurance Company, Ltd., Manchester, and is reproduced by permission of the Chief Engineer, J. F. L. Crosland, Esq.]

TO ENGINEERS-IN-CHARGE, FIREMEN,

And Others Responsible for the Upkeep and Management of Steam Boilers.

Water-Gauges should be blown through frequently, and the glasses kept clean and the passages clear. The fact that a boiler may be provided with a low-water safety-valve does not excuse lack

of vigilance as to the water level. More accidents happen from want of attention to water-gauges than from all other causes put together.

Safety-Valves should be tried at least once a day to make sure that they will act freely. To neglect, overload, tamper with, or to interfere with the construction of this important fitting leads to the most disastrous results.

Pressure-Gauges should be periodically tested for accuracy by the "Vulcan" standard gauge tester, from zero upwards to about 25 % above the working pressure, or at each "thorough" examination, and the result recorded in the report or Factory Act certificate.

Blow-off Cocks should be taken apart, examined and greased every time the boiler is cleaned. Make certain that water is not escaping when the cock is supposed to be closed.

Check Valves, or self-acting feed valves, should be taken out and examined every time the boiler is cleaned. When the feed pump is at work satisfy yourself frequently that the valve is acting.

Shortness of Water.—Low-water safety-valves should be kept in good working order and correct adjustment. Fusible plugs should be cleaned every time the boiler is emptied and the fusible alloy renewed at intervals of about six months, spare cones being kept in readiness to enable this to be done without inconvenience. Should the water get too low, the fire ought to be drawn at once, but if the furnace crown appears to be red hot the fire should be smothered with wet ashes, wet slack, or any earth that may be at hand. The damper should then be closed. If the engine is running or the feed pump delivering into the boiler, do not stop it, and do not attempt to blow off the steam until the fire is out and the overheated plates have cooled.

To Keep the Boiler in Good Repair raise steam slowly. Never light the fires till the water shows in the gauge-glass. Never empty under pressure, but allow the boiler and brickwork to cool before running the water off. The admission of oil or greasy matter into the boiler is dangerous, causing overheating of the plates, and should be carefully avoided. Clean the boiler inside

once a month, particularly if of the water-tube type, or oftener if the water is bad. Clean all flues at intervals not exceeding three months. Stop any leakages and prevent any dampness at the seating or covering. Carefully examine the plates subjected to the direct action of the fire, the inside of the boiler and the parts in contact with brickwork. If the boiler is not required for some time, or if from its exposed situation the water would be liable to become frozen, the pressure gauge should be removed and the boiler emptied and kept thoroughly dry.

To Save Coal keep the boiler clean inside and outside. If there is a plentiful supply of steam keep a thick fire, but if short of steam work with a thin fire, keeping the bars fully and evenly covered. Firing a furnace on each side alternately tends to prevent smoke.

[The following is a reproduction of the [illegible] "Wasting under Brickwork and Coverings" of [illegible] d General Insurance Company, Ltd., Manchester, and is reproduced by permission of the Chief Engineer, Edward G. Hiller, Esq.]

WASTING UNDER BRICKWORK AND COVERINGS.

The condition of those parts of boilers which are covered by flue brickwork, or composition, or other coverings, cannot be determined without the removal of the brickwork or the covering.

Serious Corrosion under brickwork often occurs, and also under composition and other coverings, where boilers are unhoused and not protected from the weather; where the surrounding ground is damp; where steam pipes and fitting joints are allowed to leak; where leakage occurs at shell seams. Even where boilers are housed and otherwise dry, leakage at the seams may cause serious corrosion.

The parts about the front cross-seating wall, and the blow-off pipe joints, are peculiarly liable to dampness, from leakage and other causes; and serious corrosion of the plate, angle iron, and blow-off pipe is often the result.

Many disastrous explosions have occurred owing to unsuspected corrosion under brickwork.

Ploughing and Baring Necessary.

TO AVOID EXPLOSION AND TO SAVE EXPENSE IN REPAIR THE FOLLOWING RULES SHOULD BE ADOPTED :—

Special Baring.—*Dampness or Leakage.*—Whenever leakage or dampness shows through brickwork (or composition covering) the brickwork or covering should be removed at once for examination and the defect made good.

All sources of external dampness should be prevented.

Periodical Baring.—*Top Coverings.*—Remove brickwork or non-porous composition, if boiler unhoused, every five years; if boiler housed, every ten years. Remove porous composition, if boiler unhoused, every ten years; if boiler housed, every fifteen years.

Flue Brickwork.—Plough flue covers, and in case of side-seating walls remove bricks, so as to push back seating blocks at each ring seam, every ten years. The gaps should be about 1 ft. wide at the covers, and 9 ins. at the seatings.

Where flue covers or seating walls are excessively wide or are liable to dampness, ploughing should be done oftener.

Where boilers are unhoused it is desirable to remove the flue covers entirely, especially if dampness exists.

If longitudinal seams come in the flue covers or under the seating walls, they should be entirely bared. The flue covers should also be removed where they come under steam and feed pipes, and supporting brackets in externally-fired boilers should be also bared.

Front cross-seating walls should be entirely removed or at least for 6 ft. circumferentially round the bottom every ten years, but every two or three years if more than 9 ins. wide, and if not clear of front end seams. If damp, they should be removed about the blow-off every year.

The composition, or lagging, of vertical boilers should be removed every five to eight years in cases where the covering is non-porous, and every seven to ten years where it is porous.

[The following is a reproduction of instructions issued by the Scottish Boiler Insurance Company, Ltd., Glasgow, and is reproduced by permission of their Chief Engineer, GEORGE NESS, Esq.]

INSTRUCTIONS TO FIREMEN.

Water-Gauges.—Try these frequently to ascertain the level of the water, and see that the passages are clear.

Feed Appliance.—Regulate this so as to keep the water as nearly as possible at the same level.

Check-Valves.—Make sure that the water is not being forced out of the boiler in consequence of these valves being defective.

Blow-off Cocks.—Examine these every time the boiler is cleaned, and see that there is no leakage going on while the boiler is at work.

Fusible Plugs.—Keep the caps free from accumulation of soot and scale, and change them at least once a year.

Safety-Valves.—Try these several times daily to ascertain that they are free in action. To prevent overloading with lever valves, have the levers cut so as to allow no more than the stipulated pressure when the weight is at the extremity.

Pressure-Gauges.—Have these tested periodically. For this purpose a suitable tap should be fitted to the boiler to which the inspector may attach his standard gauge.

Raising Steam.—In raising steam from cold water, do so slowly, allowing the boiler to become gradually and uniformly heated, thus preventing the severe strains of unequal expansion.

Firing.—In a double-flued boiler, fire each furnace alternately; by this means a steadier evaporation will be maintained, and a double volume of smoke prevented. When the furnaces are of sufficient width, throw the fuel on each side alternately, as a preventive of smoke. If there is a plentiful supply of steam, keep up a thick fire, but if rapid evaporation is necessary, work with a thin fire, spreading the fuel evenly over the bars and introducing it in small charges at short intervals.

Shortness of Water.—If this is observed before the furnace crowns become red hot, draw the fires at once. If too late, shut the damper and smother the fires with slack, sand, or earth. Do not stop the engine if working, or start it if standing ; do not lift the safety-valve lever or interfere with the feed. Do nothing further until the fires are out and the overheated plates cooled down, when the boiler must be inspected before again working.

Generally.—Never allow wet ashes to accumulate against the front end of boiler. Stop all leakages from joints and mountings; until this can be done thoroughly take means to prevent the drippings from lodging on the plates. Do not empty the boiler until the pressure is off, and the boiler and brickwork cool. When cleaning, examine all parts in contact with brickwork for signs of leakage or dampness, and where such are observed have the necessary repairs made without delay.

Thorough Examination.—When this has been arranged for, the boiler should be emptied, all manhole, mudhole, and handhole doors removed, the plates thoroughly cleaned and scaled at the waterside, and all deposit removed. The fire bars and flame bridges should be taken out, all connections opened up, safety-valves taken adrift, cleaned, and re-adjusted. The internal and external flues should be cleaned, and all soot swept off the plates, Where brickwork is damp, it should be frequently opened up.

[The following is a reproduction of instructions issued by the Ocean Accident and Guarantee Corporation, Ltd., London, and is reproduced by permission of the Directors.]

INSTRUCTIONS TO FIREMEN.

On Commencing Duty.—Look into the furnaces, see whether any bulging or leakage has taken place, and notice whether the water level has fallen during the night.

Blow through all the water-gauge taps, and raise the dampers to clear the flues of explosive gases.

Open the blow-off cock to remove any sediment.

Stir up fires and raise pressure as slowly as possible.

Try the safety-valves to make sure they act freely.

To neglect, overload, or tamper with the safety-valves leads to the most disastrous results.

Do not open the junction valve or engine-stop valve fully until you are satisfied that the steam pipes are quite free from water.

During the Day.—See that the proper level of water is always maintained and never allow it to get low.

See that the water-gauge glasses are kept clean and the passages clear, and try them frequently.

Want of proper attention to the water-gauges leads to more accidents than all other causes put together.

Keep the fire-bars evenly covered.

Firing a furnace alternately on each side and leaving the fire door partly open after firing will tend to prevent smoke.

Feel the waste pipes from the blow cocks of boiler and economiser at least once a day. If hot the taps are leaky.

After each stop, open the dampers to clear the flues of gas before breaking up the fires.

See that the boiler and its fittings are kept clean and in working order, the blow-off pit dry, and the boiler house swept and tidy.

On no account allow ashes to lie against the boilers or about the blow-off pipe and never slake them there.

Never attempt to stop a leak or tighten a joint when there is a high pressure in the boiler.

Before Leaving Duty.—Run the water up as high as is necessary and take note of the level and see that the blow-off cocks are properly shut.

Ascertain whether the steam-pipe drains are open and in working order.

Bank the fires, close the damper and tidy up.

If the Water gets too Low.—The fire ought to be drawn at once, but if it is heavy or the furnace crown appears to be red hot, smother the fire with dirt or wet ashes and close the dampers, leaving the fire door open.

Warn every person away from the boiler.

If the engine or feed pump are running do not stop them, but if not running do not start them.

Wait until the fire is out and the overheated plates have cooled before attempting to blow off the steam.

To Save Coal and Keep the Boiler in Good Repair.—Clean the boiler inside once a month or oftener if the water is of bad quality.

Also sweep the flues at intervals not exceeding three months.

Examine the seams, and especially those parts in contact with the seating brickwork, and any plates subjected to the direct action of the fire.

Always raise steam slowly and never light the fires until the water shows in the gauge glass.

When emptying the boiler never do so under pressure, but allow the boiler and brickwork to cool before running the water off.

Take every precaution to prevent the admission of oil or greasy matter into the boiler, as this is dangerous, causing overheating of the plates.

APPENDIX E

FORMS.

THE BOILER EXPLOSIONS ACTS, 1882 & 1890.

SUMMONS TO ATTEND A FORMAL INVESTIGATION.

To Mr.

TAKE NOTICE that by virtue of the provisions of the Boiler Explosions Act, 1882, 45 and 46 Vict., c. 22, we hereby require you to attend personally before us at on the day of at of the clock in the noon, for the purpose of being examined upon oath upon the following matters, that is to say, the causes and circumstances attending the explosion of a Boiler which occurred .

AND TAKE NOTICE that we also require you then and there to produce together with all books, papers or documents, which may be in your possession, or under your control, containing any information relative to the matters aforesaid.

AND WE FURTHER GIVE YOU NOTICE that under Section 7 of the said Act the Court may order the costs and expenses of this Formal Investigation, or any part thereof, to be paid by you, or any person summoned before us.

Given under our hands this day of .

Commissioner.

Commissioner.

NOTE.—Any person neglecting or refusing to attend as required by this Summons will incur a penalty not exceeding Ten Pounds.

To this form is attached the list of questions which the Board of Trade propose to ask the Commissioners at the hearing.

FORM 55.
February, 1911. [See Notes overleaf.

FACTORY AND WORKSHOP ACTS, 1901 AND 1907.

FORM PRESCRIBED BY THE SECRETARY OF STATE, FOR

REPORT OF EXAMINATION OF STEAM BOILER.

Address of Works

Name of Occupier

Description or distinctive number of Boiler, and type

Age ... ...
The history should be briefly stated, or reference made to record in earlier reports.

Date of last hydraulic test (if any), and pressure applied.

Quality and source of feed water ... ...

1. Boiler—
   (*a*) Was the boiler scaled, prepared, and (so far as its construction permits) made accessible, sufficiently for thorough examination and for such tests as may be necessary in order to complete the thorough examination?
   (See Note C overleaf.)
   (*b*) What parts (if any) were inaccessible?
   (*c*) What examination and tests were made?
   (*d*) Condition. (State any defects materially affecting the permissible working pressure.) External: Internal:
2. Mountings—
   (*a*) Are there proper mountings, including safety-valve, water-gauge and steam-gauge?
   (*b*) Are all mountings properly maintained and in good working order?
   (See Note B overleaf.)
   (*c*) Are the water-gauges protected?
3. Permissible working pressure for the ensuing 14 months (subject to any conditions stated in paragraphs 4 and 5) calculated from dimensions, and from the thickness and other data ascertained by the present examination; due allowance being made for conditions of working if unusual or exceptionally severe.
4. Repairs (if any) required, and period within which they should be executed.
5. Other observations ... ...

I certify that on I thoroughly examined the boiler above described, and that the above is a true report of the result.

Signature

Counter-signature (when required by s. 11).

Qualification

Name of Company or Association.

Address

Date

Date

[Back of Form 55.]

NOTES.

A.—The Factory and Workshop Act, 1901, s. 11, requires as follows:—

(1) Every steam boiler used for generating steam in a factory or workshop or in any place to which any of the provisions of this Act apply must, whether separate or one of a range—

(*a*) have attached to it a proper safety valve and a proper steam gauge and water gauge to show the pressure of steam and the height of water in the boiler; and

(*b*) be examined thoroughly by a competent person at least once in every fourteen months.

(2) Every such boiler, safety valve, steam gauge and water gauge must be maintained in proper condition.

(3) A report of the result of every such examination in the prescribed form, containing the prescribed particulars, shall within fourteen days be entered into or attached to the general register of the factory or workshop, and the report shall be signed by the person making the examination, and, if that person is an inspector of a boiler-inspecting company or association, by the chief engineer of the company or association.

(4) A factory or workshop in which there is a contravention of this section shall be deemed not to be kept in conformity with this Act.

(5) This section shall not apply to the boiler of any locomotive which belongs to and is used by any railway company, or to any boiler belonging to or exclusively used in the service of His Majesty.

(6) For the purposes of this section, the whole of a tenement factory or workshop shall be deemed to be one factory or workshop, and the owner shall be substituted for the occupier, and he shall register the report referred to in this section.

The occupier of the factory or workshop is responsible for seeing that the provisions of this section are fulfilled, including the employment of a *competent* person to make the examination; and in the event of default is liable to a fine not exceeding ten pounds.

B.—Where a further inspection is necessary in order to complete the thorough examination required by the Act (*e.g.*, to inspect the mountings under working conditions) a provisional entry (" reserved for supplementary report after examination under working conditions ") may be made with regard to the items in question, provided that (i) the thorough examination is completed within the statutory period of 14 months, and (ii) a supplementary report on this Form is inserted in the general register. In such a case it is not essential that the supplementary report should repeat detail, already given in the partial report, which needs no further comment; but the dates appended to the supplementary report.

should be those of both parts of the examination, and in the earlier of the two reports the certificate will need the addition of the qualifying words "subject to the reservation (noted above) of certain points for examination under working conditions," after the word "examined."

C.—According to the type of boiler, facilities must be given by the occupier for such examination (internal and external), hammer testing, drilling, lifting, hydraulic testing, steam trial, or other means of testing as may be necessary for the thorough examination. Thus, the boiler should be opened out, cleaned and scaled; doors of manholes, mudholes, and handholes taken off; fire-bars removed, and (in case of Lancashire and Cornish boilers) fire-bridges if of brick; all connections opened out; safety-valves taken adrift, cleaned and re-adjusted. Where necessary, brickwork must be removed for the purpose of inspection of vital parts of the external surface of the boiler.

A similar Form is prescribed for the examination of a steam boiler under the Coal Mines Act which comes into force July 1st, 1912.

The Coal Mines Act, 1911, s. 56, enacts as follows:—

56.—(1.) Every steam boiler used for generating steam in or about a mine* must, whether separate or one of a range—

(*a*) have attached to it, a proper safety-valve, and also a proper steam-gauge and water-gauge, to show respectively the pressure of steam and the height of water in each boiler; and

(*b*) be examined thoroughly by a competent person at least once in every fourteen months; and

(*c*) be cleaned out and examined internally, as far as the construction of the boiler will permit, by the person in charge of it once at least in every three months.

* Mines of coal, stratified ironstone, shale or fire clay. "Mine" includes shafts and inclined planes in the course of being sunk or driven and all works and tramways above and below the ground adjacent to the mine. [See Coal Mines Act, ss. 1 and 122.]

(2.) Every such boiler, safety-valve, steam-gauge, and water-gauge must be maintained in proper working condition, and all water-gauges shall be adequately protected by a covering or guard unless so constructed as to be equally safe to the persons employed whether so protected or not.

(3.) A report of the result of every examination under this section in the prescribed form and containing the prescribed particulars, shall, within fourteen days, be entered into or attached to a book to be kept at the mine for the purpose, and the report shall be signed by the person making the examination, and, if that person is an inspector of a boiler inspecting company or association, by the chief engineer of the company or association.

(4.) The foregoing provisions of this section shall not apply to the boiler of any locomotive which belongs to and is used by any railway company.

(5.) A steam boiler shall not be placed under ground in any mine after the passing of this Act.

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